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A study of calving interval

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INTRODUCTION

Efficient reproductive performance is the first prerequisite of any sound animal production program. Culminating as it does in the production of new life, reproduction is a most complex process. While both males and females are involved in the production and fertilization of the ova, the female, at least in mammals, plays the central part in the process since she bears sole responsibility for the implantation, development and birth of the offspring.

In order to evaluate reproductive performance, various measures of fertility or breeding efficiency have been proposed. According to Maijala (1964) and Foote (1970), the most common measurements used in cattle include: calving interval, conception rate, percentage of animals which do not return to service by 60 or 90 days, and the number of services required for conception. There is considerable confusion over the definitions of such measurements. Because of this it is difficult to compare results from much of the published literature and to draw inference from it. Even so, it has consistently been shown that environmental factors have major effects on reproductive performance. In cattle, most of the research in the field of reproduction has been with dairy cattle. Genetic aspects of breeding efficiency in beef cattle have been discussed by Brakel *et al.* (1952) and Brown *et al.* (1954). Genetics is usually regarded as an unimportant source of variation but this is based on the fact that estimates of heritability measured within breeds are low (Legates, 1954; Maijala, 1964; Foote, 1970). However, there is evidence that nonadditive genetic variation is quite important. Heterosis up to 25% has been reported from crossbreeds compared with straightbreds by Lush (1945), Mason (1966) and Pearson and McDowell (1968). Also, differences between breeds certainly do exist (Everett et al., 1966; Gaines et al., 1966 and McDowell et al., 1970). There is no information about the comparative fertility of beef and dairy types when kept together under similar conditions.

Although environment plays the most important part in accounting for variation, there is relatively little information about the specific effect of the various factors, which together constitute that environment. Among the environmental factors which seem to have an important influence on reproductive performance are nutrition, location, calving season and the herd management system (VanDemark, 1954 and Cundiff and Gregory, 1968). Minor effects of age of dam, season of year and time trends were reported by Pou et al. (1953) and Krehbiel et al. (1969).

There appears to be no published comparison of the reproductive performance of beef and dairy cattle kept under similar conditions. One purpose of the present study was to compare the fertility of two dairy and two beef breeds kept together for beef purposes. The animals were representatives of the Angus, Hereford, Holstein and Brown Swiss breeds. Another purpose was to examine differences in estimators of breeding efficiency between cows which calved one, twice or three times over a three-year period. Also, the importance of various environmental factors on reproductive performance was considered.

REVIEW OF LITERATURE

Fertility Traits in General

Numerous investigations have been made into the reproduction of cattle using field data. Field data are defined as accumulated data from experiments that were not planned specifically for studying reproductive performance. Among the various measurements of fertility, the following have been used: 1st, length of calving interval; 2nd, days open; 3rd, interval between calving and first heat; 4th, interval between first service and conception; 5th, number of services per conception; 6th, percentage of nonreturns to first service; 7th, service period, etc. There is, however, some confusion over the definition of these measurements. In some cases, one of them may include several of the others. Most of the studies investigated genetic parameters. In general, there is agreement in the literature that values of heritability and repeatability are very low or zero for measures of fertility, often referred to as breeding efficiency. Legates (1954) concluded that very little additive variance appears to be left in reproductive characters. Most of the published studies involve dairy cattle. There is a lack of information on beef cattle or dairy animals used for beef purposes. Even though the additive genetic variance is likely to be small, breed differences and heterosis estimates suggest that the total genetic variance is considerable

(Gaines et al., 1966: Mason, 1966; Wiltbank et al., 1967; Donald and Russell, 1968; Pearson and McDowell, 1968; Turner et al., 1968 and Rollins et al., 1969).

The environment is recognized as an important influence on reproductive efficiency but there is very little information about the nature or relative importance of the factors which constitute the total environmental effect.

Very few studies have been made to compare the different estimators of fertility using the same data, although Pou et al. (1953), Carman (1955), Maijala (1964) and Everett et al. (1966) are among those who have made such comparisons.

In spite of the low heritability reported, some research workers have attempted to construct indexes or scores for reproductive efficiency (Buschner et al., 1950; Olds and Seath, 1950; Plum et al., 1965). Evaluation which includes control of the environment by management has been suggested by Spielman and Jones (1939), Buschner et al. (1950), Johnson et al. (1964), Ødegård (1965) and Tudorascu (1968).

In this study, reproductive traits are studied in a sequence of time. Four measurements which met this requirement will be reviewed. They are as follows: 1st, the interval between parturition and first recorded service (postpartum interval); 2nd, the period between first recorded service and the service after which conception occurred (conception length); 3rd, length of gestation period (gestation length); and 4th, the sum of the three or the interval between two consecutive parturitions (calving interval).

Calving Interval

Calving interval is defined as the period of time elapsing between two consecutive parturitions. The calving interval comprises the interval from calving to first heat (postpartum interval), number and length of services of the cow until pregnancy (conception length), and the length of gestation. In addition, other fertility indexes such as: (a) conception rate, (b) number of services to establish conception, (c) rebreeding rates, and (d) incidence of barrenness, to quote some of them, can be studied as components of calving interval in a population. An additive relationship exists between postpartum interval, conception length and gestation length as components of calving interval. Different factors contribute to the variation of calving interval. Some of them depend largely upon the genetic material and others only on the environment or the interaction between genetic and environmental factors. The advantages and disadvantages of calving interval as a measure of reproductive efficiency have been discussed in detail by Johansson (1961) and Maijala (1964) with reference to dairy cattle. Johansson (1961) pointed out that data will be rather highly selected since at least two parturitions are required and even more so when the data are used to calculate heritability and repeatability. Besides, the length of the calving interval may be greatly affected by management; the breeder may intentionally increase or decrease the length of the interval for certain cows. Maijala (1964) observed that calving interval is one of the most commonly used measures of fertility. This measure can be determined accurately and objectively and moreover it is a continuous variable and almost all causes of sterility have an influence on it. He points out that the accurate determination of calving intervals is sometimes made difficult by abortions of varying durations. A disadvantage is that calving interval does not reveal the absolutely sterile heifer or the breeding abnormalities of cows culled before their second calving.

One of the first to use calving interval as a measure of fertility was Albrechtsen (1916) cited in Maijala (1964), who employed it for comparing average fertilities of different herds.

Williams (1919) developed an expression to measure reproduction using 12 months as a base for the ideal calving interval and assuming that a heifer must calve at the age of two years. All months after this age were called by him "breeding months". The expression derived was (number of calvings x 12 x 100)/(number of breeding months).

Spielman and Jones (1939) worked on the same concept but suggested a new formula in which they replaced the number of breeding months by the number of months since the first calving. A correlation as high as 0.55 was observed between the reproductive efficiencies of dam and daughters. In addition, a marked difference in reproduction between various cow groups and between breeds was noted in the herd studied.

Gaines and Palfrey (1931) analyzed data from Red Danish cows. They reported a negative correlation between calving interval and average milk yield, and a positive correlation between calving interval and yield over the following calving interval. The mean of the calving interval was 401 days.

Rennie (1952) studied data from two Holstein herds and reported a mean interval of 413 days. He found that the age at first calving had practically no influence on length of calving intervals. He also reported that a high positive genetic correlation exists between length of calving interval and milk and fat production. The correlation between the different calving intervals of a cow was 0.17. Due to large sampling errors, he concluded that the true heritability of calving interval is very low.

Brown *et al*. (1954) reported a mean of 15.4, 14.3, and 12.9 months for first, second and third calving interval respectively in an Angus herd. Heritability of calving interval was practically zero, when studied using the paternal half-sib correlation and intrasire, daughter-dam regression methods. The repeatability of calving intervals was also zero. Sequence and year contributed 17.5 and 6.7 percent respectively, to the total variance.

Legates (1954) reported for Holstein cows a mean interval of 406 days and that heritability was zero, although repeatability was 0.13. On the contrary, Wilcox et al. (1957) reported that the heritability of breeding efficiency based on calving interval was 0.32. The data analyzed came from a 30-year period and the effects of longevity and selection of the cows were involved. The correlation between longevity and breeding efficiency was nearly zero.

Using records from Norwegian Red Cattle, Ødegård (1965) undertook a study on intervals between first and second calving (calving interval I) and intervals between second and third calving (calving interval II). He found no significant relationship between daily milk yield and calving interval I and II. The calving intervals were influenced significantly by the season of calving. Calving interval I was on an average somewhat longer than calving interval II. Repeatability for calving interval, calculated as the correlation between calving interval I and calving interval II, was close to zero.

Everett et al. (1966) found an average of 387 days for the calving interval of Holstein cows. Heritability was reported as 0.08 and repeatability was zero. They suggested that calving interval may be considered to be composed of two constants, parturition to first breeding and gestation length, and a variable, first breeding to conception which has the final influence on length of calving interval.

Cundiff and Gregory (1968) gave a heritability estimate of 0.10 for calving interval. They pointed out the importance of adequate levels of energy intake by the cow in the weeks from calving to breeding. Similar findings resulted for heifers in the weeks just prior to the breeding season. This strongly affects their calving performance as two-year-olds. In a review of estimators of fertility, Foote (1970) reported an estimated heritability of calving interval of zero. He concluded that there is no doubt that fertility has a genetic basis but additive genetic variance is very small. He remarked that calving interval and milk production are genetically correlated in dairy cows, but with the low heritability of calving interval, little change in this interval is expected from selecting for production.

Postpartum Interval

The postpartum interval is defined as the period of time (in days) between parturition and the first recorded service. This period can be delayed intentionally by breeders and is dependent on the management system. Variation occurs in this period, resulting from cow differences and the management practices of the breeding herd. The external manifestation of estrus (heat) contributes to the variation in this period, since not all cows exhibit the same estrous behavior. Some show weak external manifestation or "silent" estrous and as a result are not bred. On the other hand, dairy or beef cattle are often mated after a fixed period following the average parturition date. Breeding seasons are typical in beef production.

Postpartum interval has been investigated extensively in the dairy cow because this period is important in determining the optimum interval between calving and the first service or mating to maximize milk production. Olds and Seath (1953) analyzed breeding and milk records from the dairy herd of the Kentucky Agricultural Experiment Station. The average length of time from calving to first estrous for 210 cows who had normal parturitions was 32.1 days. Analysis of the data indicated that individual cows had a tendency to repeat the length of time between calving and first estrous at successive parturitions. It appears that one previous observation on a cow would eliminate about 29 percent of the total phenotypic variance in predicting future intervals between calving and first estrous. Chapman and Casida (1935), investigating the service period (number of days from calving to last service) found averages in 8 herds that ranged from 120 to 180 days. The average length of service period in one herd was 150 days, of which 120 days was postpartum interval and 30 days was from first service to conception. They pointed out that the period from parturition to first estrus was too long for early conception. On the average, 50% of these periods were less than 61 days in length, 40% were between 61-120 days and the remaining 10% were over 120 days in length. In a study of breeding and production records of 10,907 Holstein and 10,537 Guernsey lactations in California, Everett et al. (1966) reported a mean of 107 for days open, 78 days from parturition to first breeding and 29 days from first breeding to conception for Holstein. For Guernsey, the figures were 107, 75 and 32 respectively. A period of 55 days was allowed to elapse before first breeding. The three days more from parturition to first breeding for Holsteins compared to Guernseys corresponded to a decrease of 0.18 services per conception and a decrease of three days in first breeding to conception. Parturition to first breeding was uncorrelated genetically with the interval between first breeding and conception, but the latter was highly correlated genetically with days open. In a summary of eight papers, Casida et al. (1968) indicated that different percentages of first inseminations are fertile depending on the length of the postpartum interval. Data were summarized for dairy and beef cows separately since the management of breeding differed. For the beef cows, natural service was practiced with the cows being bred at the first estrus after calving. In the case of the dairy cows, artificial and natural service were both used, but breeding was more often delayed until a later estrus. Unweighted averages of the reported fertility data for the successive months after calving were calculated using the first six months after calving for the dairy cattle and the first four months in the case of the beef cattle. The averages for conception at first service were 39.3, 53.2, 61.6, 62.2, 64.7 and 64.3 percent for the first six consecutive months for the dairy cattle and 33.4, 58.1, 68.6 and 74.4 percent for the first four months for the beef cows. Auran (1970) studied factors affecting reproduction in cows using records from the Norwegian milk records. With data from 98,304 cows of the Norwegian Red Breed, he studied reproduction by service period. The mean length of the service period was found to be 94.0 days. He found an average of 1.5 estrous periods involved in the 94.0 days. Thus, the average postpartum interval was about 62 days. No consistent connection was found between herd milk yield and the length of the service period. Estimates of genetic parameters for breeding efficiency were found to be very low. These would be of little use in predicting future records or in making genetic progress.

Carman (1955) analyzed data from 1,646 lactations of 763 cows from a Holstein herd at Iowa State College and another at Cherokee, Iowa, belonging to the State Board of Control. He found a mean for postpartum interval of 55.4 days for the first farm and 71.0 days for the second one. There was no evidence of additive genetic variation at all and repeatabilities were on the order of 0.15 and 0.25, respectively, for each farm. He also found that the period between parturition to first estrus was significantly correlated with the level of milk production in the succeeding lactation. Smith and Legates (1962) reported heritability estimates for days open ranging from 0.01 in first lactations to 0.09 for all records. The number of days open for all lactations followed by a normal calving was computed by subtracting a 280 day gestation period from the calving interval. The mean for days open at first lactation was 143 days. Over all lactations, the mean days open was 145 days.

Ødegård (1965) examined fertility data from groups of heifers which had been collected for the purpose of sire progeny testing. Number of days from first calving to first apparent heat period and 2 calving intervals among other records were included. No significant relationship was found between maximum milk yield and the different fertility characteristics. The estimated value for the heritability of the interval between calving and first heat was 0.13.

The length of postpartum interval had been related to fertility of the cow by different authors. In a study of 1,674 pregnancies in 593 cows of the University of Illinois dairy herd, VanDemark and Salisbury (1950) showed that fertility increased with the length of the postpartum interval up to 100-120 days. The relationship between the interval from calving to first service and reproductive efficiency, measured as conception, was curvilinear and not significant.

Branton et al. (1956) analyzed Holstein data from 1931 through 1946 at Louisiana State University. Records pertained to 381 cows representing offspring of 15 sires. The postpartum interval, the season of the year, and genital diseases such as brucellosis and vibrosis were found to influence fertility markedly when it was measured as number of services per conception.

Tudorascu (1968) concluded that fertility subsequent to first insemination and mean service-period time for cows inseminated for the first time at various intervals postpartum could be described by an ascending curve from the first to the fourth month, as well as from the subgroups of animals with high milk yields to those with low milk outputs. Fertility subsequent to the second and third insemination was independent of the interval to first heat. He pointed out that in estimating insemination efficiency at various intervals postpartum, the service period should be taken into account, together with the fertility ratio subsequent to the first insemination and the insemination rate.

Variation in the duration of postpartum interval is in part due to the biological variation in the interval from parturition to first estrus and in part to the management practices in the herd. The biological variation has been studied by several workers. These findings will be summarized briefly.

Morrow et al. (1966) reported that the time period needed for uterine involution to occur in dairy cows is 25 days. This conclusion was based primarily on rectal palpations and clinical observation. Buch et al. (1955) found this interval in Holsteins to be 50 days. The time of first ovulation has been reported as 35 days by Casida and Wisnicky (1950), 19 days by Menge et al. (1962), 15 days by Morrow et al. (1966) and 14 days postpartum by Wagner and Hansel (1969).

Nursing by calves delays the return to postpartum cyclic activity and depresses fertility according to Wiltbank and Cook (1958). Non-suckled cows returned to estrus in a shorter time following calving than suckled cows in all four experiments reported by Graves et al. (1968). Regeneration of the surface epithelium over the caruncles was complete in most animals by day 25 postpartum according to Gier and Marion (1968) and day 30 according to Wagner and Hansel (1969). Riesen et al. (1968) reported that the rate of uterine involution was more rapid for suckled than non-suckled animals in the one to ten day period and the twenty to thirty day postpartum period. This increased rate resulted in the suckled animals being nearly involuted by 30 days postpartum while non-suckled cows were not involuted at either 30 days postpartum or during the first estrous cycles. On this ground, clinicians have discouraged the practice of early breeding following calving. Artificial insemination organizations too have discouraged early breeding because the conception rate is lower than if breeding is delayed for 2 1/2 or more months.

Conception Length

Many statistics have been suggested to measure fertility, _per se_, in the cow, e.g., number of services per conception, percentage of nonreturns to the first service or conception rate, regularity of the occurrence of estrus and the number of days or interval from first service to conception which in this study is called conception length. Conception length is defined as the period between the first recorded service and the service of conception. A conception is defined if it terminates in the birth of a calf or abortion. Embryonic deaths and short-term abortions were not considered as conception. The assumption is that any cow is bred as long as she shows estrus and that during this period there is no deliberate delay. Bias could occur in this measurement because of failure to detect estrus on the part of the breeder and cows which exhibit signs of heat weakly would be particularly liable to be discriminated against.

Conception length in cows is a function of estrous cycles, fertilization, and implantation of the fertilized ova. Thus, the female plays a particularly important part in the whole process.

Conception length and its relationship to other reproductive traits has not been studied extensively; however, some studies have been reported. Buschner *et al.* (1950) used the interval from first breeding to conception simultaneously with postpartum intervals, to devise a score of reproductive efficiency in dairy cattle. These measures were used to predict age of the animal at 3rd calving. Based upon age at first breeding and the interval from first breeding to conception, most of the variation in age of cow at 3rd calving could be explained.

Johansson (1961) judged that the number of services per conception, nonreturn rate to first service or interval between first service to conception would be the best measures of the fertility status of the cow, because they are probably less influenced by planned efforts of the breeder and selection is easier to avoid. Even data on heifers can be included. Using services per conception as a base, the genetic correlation between days open and the interval from first breeding to conception indicate that they are a measure of approximately the same gene effects. Everett *et al.* (1966) concluded that days open are essentially determined by the interval from first breeding to conception. They pointed out that services per conception and the interval from first breeding to conception are, fcr practical purpose, measures of the same variable.

The genetic and environmental variability of estimators related to conception length have been investigated by different research workers. Tabler et al. (1951) studied breeding efficiency of Ayrshire cow families and found that for services per conception and the average number of days from first breeding to conception, there was more variation within families than between families. They concluded that error variance explained more than half the total variation in every characteristic studied.

Pou et al. (1953) examined 834 records of cows from the Beltsville dairy herd and obtained a repeatability estimate of 11% and a heritability estimate of 7% for the number of days from first service to conception. These figures are almost exactly the same as those obtained for the number of services required for conception in the same herd. Carman (1955), studying two herds in Iowa, found that the mean for days to conception from first service was 28 in one herd and was 42 in the other. He reported that the repeatability and heritability of breeding efficiency, when these are measured by days to first estrous, days to conception, and services per conception, are all zero or nearly so.

Donald and Russell (1968) undertook a study on fertility in three straightbreds and their crosses in Britain. The breeds were Friesian, Ayrshire and Jersey. Number of services per conception seemed a less satisfactory measure of reproduction than conceptions to first service because some animals were arbitrarily classed as barren for a variety of reasons and excluded from the calculation. No effect of age on conception rate in heifers was established except possibly with respect to barrenness. Among cows, those of 27 months or less, 10% were less fertile than older cows. The reduction of variance in number of services obtained by fitting values for breeds of male and female, types of crosses, season and year of service was small. These variables amounted to 5.5% of the total variance in the number of services required for first conception and 13.7% of the total variance for second conceptions. In a review of inheritance of fertility, Foote (1970) indicates that conception rates of heifers and cows showing weak symptoms of estrus were low, but within progeny groups, the correlations between conception rates and expression of estrus also were low. Thus, while the manifestations of estrus are useful in predicting the probability of conception of an animal inseminated at the time, they are not very useful in improving breeding efficiency by selection. Concerning days to conception, the literature reviewed (non-returns and services per conception) show that the additive genetic differences for fertility among cows are small.

Some other statistics highly correlated with conception length are services per conception, conception rate at first service and nonreturn rates at a defined period. Much of this correlation is expected because these are different ways to measure a specific parameter of fertility: conception. The advantages and disadvantages of these estimators will not be discussed in detail here, but some references will be helpful for further discussion.

Studying services per conception, Branton et al. (1956) found heritability and repeatability estimates of 0.10 and 0.11 respectively in dairy cattle. Legates (1954) analyzed field data from dairy herds and found an average of 1.80 service per conception and a heritability of 0.03. Evidence from these studies indicate little existing genetic variability in service per conception.

Collins et al. (1962), analyzing data of two Guernsey herds, calculated heritability estimates of 0.02 and 0.08 for conception rate at first service. Inskeep et al. (1961) reported a heritability of 0.09 for a Holstein herd. Foote and Hall (1954) examined nonreturn rates as a measurement of fertility from a large amount of Holstein field data. Using percent nonreturn by 150-180 days for cows inseminated 1, 2, 3, 4, 5, 6, 7 or more times, they found that the figure decreased as the number of service increased. The same was true for conception rate. A maximum decrease of 45% was reported.

Olds and Seath (1950) used nonreturns at four months as a reasonable approximation of actual conception in analyzing data over two years. As the number of services required by cows the first year increased, there was a rather uniform increase in the average number of services required the second year. Nearly 55 percent of the cows required the same number of services both years.

Gestation Length

Gestation can be defined as the time needed for complete development of the ova from fertilization to parturition. The time between conception and calving is defined as gestation length.

The complete development of the fertilized ova into a new individual depends largely upon the genetic material at least in straightbred comparisons. Differences between breeds have been reported by Livesay and Bee (1945), Alexander (1950), Andersen and Plum (1965) and BreDahl (1970). Interruption of the gestation or abortion can occur at any time during the period. Isolated reports of prolonged gestations have appeared, Rollinson (1955), Rollins *et al.* (1956) and Pirchner (1969). The fetus may continue to grow until normal parturition is impossible. In some cases, a recessive gene has been associated with this condition (Pirchner, 1969) and in others some physiological disturbance which seemed to be hereditary has been suggested (Kennedy *et al.*, 1957).

The calf is mainly responsible for the length of the gestation period. Nevertheless some external factors which could suppress, delay or shorten gestation length have been reported by Adams (1969), Adams and Wagner (1970), BreDahl (1970), and Wright *et al.* (1970).

Brakel *et al.* (1952) reported estimates of 288.4 and 278.2 days for gestation length in Brown Swiss and Holstein cows respectively. There is evidence of genetic influence in the difference of the means of these two breeds.

Burris and Blunn (1952) gave estimates of 281.7 and 286.1 days for Angus and Hereford cows, respectively. Konce (1968) reported a gestation length of 286.6 days for Hereford cows. DeFries *et al.* (1958) reported gestation length of 279.6 and 291.5 for Holstein and Brown Swiss cows respectively. Plum *et al.* (1965), working with Holstein records, reported an estimate of 277.4 days for gestation length. Jafar *et al.* (1950) found an average length of 278.2 for Holstein cows. The sex order in calving had a significant effect. Characteristics of the calf (weight, straightbred or crossbred, etc.) seemed about three times as important as the characteristics of the dam.

Estimates of heritability have been reported from 0 to

0.71 by Andersen and Plum (1965) and Plum et al. (1965). Konce (1968) found a heritability estimate computed from a paternal half sib analysis of 0.36 and a repeatability of 0.27 obtained by the correlation between repeated records by the same dam for Hereford cattle.

Everett and Magee (1965) studied birth weight and gestation length among Holstein cows. They found the mean gestation period to be 278.9 days and that male calves were carried, on the average, one day longer than heifers. Heritability of gestation length was reported as 0.10. BreDahl (1970) reported estimates of gestation period of 286.2, 284.2, 280.1 and 277.0 days for Brown Swiss, Hereford, Angus and Holstein. He also found that the gestation length for males was 1.0 day longer than for females. On the contrary, Livesay and Bee (1945) could not find sex differences in gestation length of Angus, Hereford, Jersey, Ayrshire or Holstein; although definite breed differences were noticed.

Summary of the Reviewed Literature

Most of the literature reviewed came from dairy cattle data and very little from beef cattle data. Additive genetic variance for the different traits studied seems to be very small, except for gestation length. There is agreement in the literature cited that differences between breeds in gestation length exist and a genetic base is inferred.

Postpartum interval is highly influenced by management systems, but is responsible for a large part of the variation in calving interval. Within this period, suckling has been reported to have a marked influence on the involution of the uterus and a minor effect on the onset of first estrus. Less variability could be expected in beef cattle since the usual goal is to have a calf each year and no delay in breeding is intentionally made because of daily milk production. On the other hand, postpartum interval has been associated with fertility in dairy cows. A minimum of days for postpartum interval is required to reach the maximum of fertility. At least in dairy cattle, an increase of fertility is observed for an increase in the length of the postpartum interval until around 100-120 days.

Conception length and number of services for conception have been reported as the best measures of the fertility status of the cow. These estimators of fertility have been found to be more variable than any of the other traits studied. No factor or factors can explain their variability except the nature of the individual. Other statistics related to conception length such as nonreturn to first service, have shown the same properties in statistical analysis.

Calving interval has been reported to be one of the most commonly used measures of fertility. Any kind of estimator of fertility has an influence on it, but it is biased because records inevitably come from a selected group of animals in the population. Reports from data of dairy cows indicate that postpartum interval is responsible for most of the variation in calving interval while others indicate that conception length is the one that has the ultimate influence on calving interval. For dairy cattle, a small positive genetic correlation between calving interval and milk production is reported. One study on Angus cows showed a similar pattern as that found in dairy cows as far as heritability and repeatability estimates are concerned. There is very little information from dairy cattle and none from beef animals concerning the nature of the factors which influence calving interval or any of its component periods.

SOURCE OF DATA

Source of Data

Data for this study came from a project designed to investigate the performance of straightbred and crossbred beef and dairy cattle of the Angus, Hereford, Holstein and Brown Swiss breeds. Records were taken from 1,303 calvings during 1968, 1969 and 1970, involving all mating combinations of the four breeds. The data were collected at two Iowa State University research farms.

BreDahl (1970) reported the origin, management, nutritional levels and breeding system of the total 800 purchased heifers during 1968 and 1969. No major change was made during the year 1970.

The 800 purchased heifers came from various sources of origin. Half the heifers from each source were assigned at random to one of two farms. A farm-bred group, consisting of 100 heifers, was randomly allocated into two pens, making a total of eight pens at each farm during the first two years of the project. Due to the breeding of heifers produced on the farms, cows were bred in breed lots and were moved to a sheltered area after the first breeding.

Breeding seasons

During the first year (1968) the estrous cycles of the animals were synchronized using melengestrol acetate in the form marketed as MGA by The Upjohn Company, Kalamazoo, Michigan. Each heifer was fed 1 mg of MGA in 14 pounds of corn for 14 days prior to breeding. No synchronization procedures were used in the following years. The length of the first breeding season (started January 1, 1968) was 60 days. Heat detection was made by direct observation and all breedings were artificial. This structure of the 1968 breeding season differs from those of 1968-9 and 1969-70 in that estrus was not synchronized and the breeding seasons lasted approximately 90 days. Open heifers (nonpregnant) were held and bred starting in December for the 1968-9 breeding season. Heifers with calf were bred starting in January. After the pregnancy examination in May of 1969, all open animals were removed from the project. In the 1969-70 breeding season, in addition to artificial insemination, natural service (hand mating) was used with young bulls (yearlings). No attempt was made to correct data according to whether natural service or artificial was used.

The first calf crop was weaned (in 1969) at 90 days. The second calf crop was weaned (in 1970) at 90 days at farm 2 but at farm 1 weaning was at 180 days because the majority of cows were cycling normally.

Calving season

Most of the dairy cows had recorded dates of birth, but as there were no such records for the beef cattle, age of dam was ignored in the analysis. All of the cows that calved in 1968 were at least two years old. The first calf crop was born through October and November 1968. Four hundred and seventy calvings were recorded.

In 1969, calves were born from September through December and 474 calvings were recorded. On farm 1, 205 cows calved for the second time and 91 did so on farm 2. Sixty cows were disposed of from farm 1 and 113 from farm 2 prior to the breeding season 1969-70 (see Table 8). The only reason for disposal was that the cow was open, as indicated by pregnancy examination.

The 1970 calf crop was born in August through December and 359 calvings were recorded. One hundred and forty-one cows calved their third consecutive calf on farm 1 and sixty on farm 2. Although the breeding season started at a definite time, there was wide variation in the time of calving within and between farms. A classification of the cows according to calving date was therefore made as shown in Table 1.

An interval of 14 days was chosen, based on a prior analysis of the distribution of the data. The first calving period was made longer because there would have been too few animals in this group otherwise.

One hundred ninety-two cows calving in 1969 were injected with the compound dexamethasone in the form marketed

Table 1. Calving period classification

Period	Day of calving[a]	Intervals of days
1	201 - 256	56
2	257 - 270	14
3	271 - 284	14
4	285 - 298	14
5	299 - 312	14
6	313 - 326	14
7	327 - 340	14
8	341 - 354	14

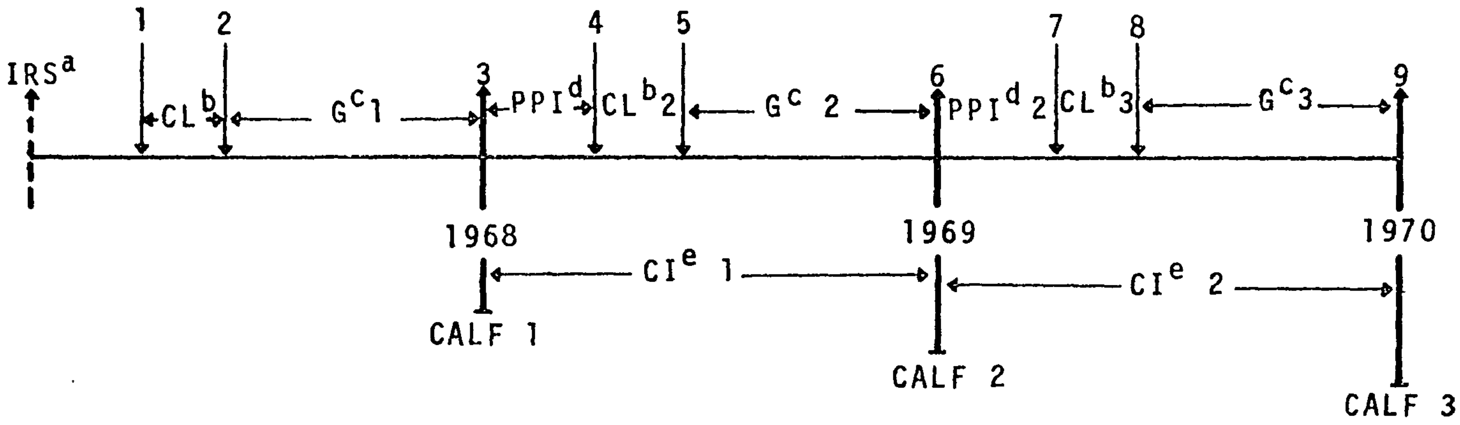
[a]Day of the year

as Azium by Schering Corporation, Bloomfield, New Jersey, and 298 cows calving in 1970 were injected with either Azium or the compound flumethasone in the form marketed as Flucort by Syntex Laboratories Inc., Palo Alto, California. This was done to conclude the calving season by the second week in December. This treatment was not used in 1968. Retained fetal membranes was one of the complications after induced parturition. No postpartum treatment was given the cows calving by Azium in 1969. In 1970, all cows that retained their placenta were treated with 20 c.c. of combiotic within five days after calving.

Structure and composition of the data

In the discussion of the subject, the time sequence or the order in which events occur is of primary importance. The starting point was the status of the reproductive system of the heifer shortly after purchase. This was deduced through rectal palpation by a veterinarian. Those heifers that were light in weight and showed no signs of ovarian activity, were eliminated. All cows detected in heat were bred. If the breeding resulted in conception, the individual produced her first calf in 1968. Following parturition, the cow was bred after a period of time defined as the postpartum interval. If the service resulted in conception, the period of time from first service to that conception was defined as conception length. Any conception was the beginning of a gestation which could result in parturition or in abortion. Cows that might have had embryonic deaths or short-term abortions, were considered as open (nonpregnant) in this study. The sequence of events (postpartum interval, conception length and gestation length) described could have been repeated as long as the cow was maintained in the herd. Any of the components of this sequence could be missed, but since this cycle is a sequence in time, the lack of the last components of the sequence do not imply the absence of the preceding components (see Figure 1).

Various genetic and environmental factors may influence



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[a]IRS = Initial reproduction status; [b]CL = Conception length; [c]G = Gestation length; [d]PPI = Postpartum interval; [e]CI = Calving interval.

1,4 and 7 = The first recorded service in the corresponding year.
2,5 and 8 = The conception's service in the corresponding year.
3,6 and 9 = Parturition in the corresponding year.

FIGURE 1. SCHEMATIC STRUCTURE OF THE DATA.

the reproductive traits chosen. Their effect may be different in the case of highly fertile cows (three calvings) compared with less fertile cows. In order to evaluate this, cows were classified according to whether or not they calved in any one year. With three years, four different classes were obtained: three classes had one calving (Group 1, 2 and 3) or two calvings (Groups 4, 5 and 6). One class had three calvings (Group 7) and one class had no calving at all (Group 8). Table 2 shows this grouping classification.

Table 2. Classification of cows by groups, year and number of calvings

Groups / Years	1968	1969	1970
1	*[a]		
2		*[a]	
3			*[a]
4	*[a]	*[a]	
5		*[a]	*[a]
6	*[a]		*[a]
7	*[a]	*[a]	*[a]
8			

[a]*Cows calving.

Table 3. Farm 1. Numbers of calving cows by groups and breeds

Breeds	Group 1[a]	Group 2[a]	Group 3[a]	Group 4[a]	Group 5[a]	Group 6[a]	Group 7[a]	Group 8[a]	Totals
Angus	9	6	0	8	28	4	35	10	100
Hereford	19	4	0	19	16	1	32	9	100
Holstein	11	2	0	18	12	5	48	4	100
Brown Swiss	19	9	0	19	5	4	26	18	100
Totals by groups	58	21	0	64	61	14	141	41	
Totals by calving		79			139		141	41	400

[a]Coding for groups in this table and all subsequent tables: 1 = 1 calving (1968); 2 = 1 calving (1969); 3 = 1 calving (1970); 4 = 2 calving (1968, 1969); 5 = 2 calving (1969, 1970); 6 = 2 calving (1968, 1970); 7 = 3 calving (1968, 1969, 1970); 8 = no calving any year.

Table 4. Farm 2. Number of calving cows by groups and breeds

Breeds	Group 1[a]	Group 2[a]	Group 3[a]	Group 4[a]	Group 5[a]	Group 6[a]	Group 7[a]	Group 8[a]	Totals
Angus	12	4	0	5	23	3	21	32	100
Hereford	17	5	1	10	17	1	19	30	100
Holstein	32	8	0	11	11	2	17	19	100
Brown Swiss	30	9	1	5	19	5	3	28	100
Totals by groups	91	26	2	31	70	11	60	109	
Totals by calving		119			112		60	109	400

The number of animals in each group by breed of cow is given in Table 3 for farm 1 and in Table 4 for farm 2. These figures total 100 animals for each breed, which is the initial number for each breed. Very few animals are shown in groups 3 and 6. This is because they should have been disposed of in 1969 but remained in the herd.

Table 5 gives the calving distribution by farms, breeds and years. Total number of barren cows refers to the total number of animals which, at the time of disposal, had not had a calf. These animals were kept two or three years in the herd.

The postpartum interval was calculated for each cow by subtracting the birthday of her calf from the date of the subsequent first recorded service. In order to calculate true conception date (true defined as being compatible with gestation length), the length of gestation was calculated first. The length of gestation was obtained by subtracting the conception date from the birthday of the calf. A normal gestation was considered not to exceed 295 days for any breed. After a careful check of the records, little doubt remained that gestations which were recorded as exceeding 295 days were due to failure by the herdman to note the service of conception. With the conception date fixed in this way, conception length was calculated by subtracting the date of first recorded service from the day of conception. These statistics

Table 5. Calving distribution by farms, breeds and years

Breed of cow	Farm 1 Barren	Farm 1 Total	Farm 1 1968	Farm 1 1969	Farm 1 1970	Farm 2 1968	Farm 2 1969	Farm 2 1970	Farm 2 Total	Farm 2 Barren
Angus	10	200	56	77	67	41	53	47	141	32
Hereford	9	191	71	71	49	47	51	38	136	3[illegible]
Holstein	4	227	82	80	65	62	47	30	139	19
Brown Swiss	18	162	68	59	35	43	36	28	107	28
Totals	41	780	277	287	216	193	187	143	523	109
By farms				780			523			
Total calvings					1303					
Total barrenness					150					

(postpartum interval, conception length and gestation length) sum, of course, to the calving interval.

Since level of nutrition has been reported to have a major effect on reproductive performance and is related to weight gain (Cundiff and Gregory, 1968), a precalving and postcalving average daily gain was calculated. Precalving average daily gain was calculated for each cow by measuring the weight 60 days, on the average, prior to calving from the weight at parturition. Postcalving average daily gain until an average of 60 days after calving was calculated for each cow in a similar manner. Tables 6 and 7 give the means for precalving and postcalving weight respectively by years and breed of cow. In this study, birth weight of the calf and the precalving and postcalving average daily gain of the dams was measured in pounds.

Table 8 gives the number of cows exposed and the number of cows calving by farm, breed and years.

Treatment indicates the use of Azium or Flucort for a cow. Twenty mg of Azium or 10 mg of Flucort was given to each cow (Adams and Wagner, 1970).

Table 6. Means of average precalving weight gain by years and breed of cow

Breed	Precalving average daily gain					
	1968		1969		1970	
	A.D.G.[a]	No.	A.D.G.	No.	A.D.G.	No.
Angus 1[b]	-1.13	55	-0.22	76	-0.44	74
Angus 2[b]	-0.92	38	-1.01	50	-0.50	49
Breed average	-1.04	93	-0.53	126	-0.46	123
Hereford 1	-1.28	70	-0.48	68	-0.55	47
Hereford 2	-0.81	34	-0.95	50	-0.31	36
Breed average	-1.13	104	-0.68	118	-0.45	83
Holstein 1	-1.70	82	-0.25	79	-0.44	64
Holstein 2	-1.53	45	-1.24	47	-0.72	26
Breed average	-1.64	127	-0.62	126	-0.52	86
Brown Swiss 1	-1.77	68	-0.29	57	-0.01	31
Brown Swiss 2	-1.05	28	-1.19	44	-0.67	24
Breed average	-1.56	96	-0.62	101	-0.30	55

[a]A.D.G. = Average daily gain approximately 60 days before calving in pounds.

[b]1 = Farm 1; 2 = Farm 2.

Table 7. Means of average postcalving weight gain by years and breed of cow

Breed	Postcalving average daily gain			
	1968		1969	
	A.D.G.[a]	No.	A.D.G.[a]	No.
Angus 1[b]	0.61	55	0.12	77
Angus 2[b]	-0.25	37	1.04	52
Breed average	0.23	92	0.49	129
Hereford 1	0.58	71	0.23	68
Hereford 2	-0.14	42	1.05	49
Breed average	0.31	113	0.57	117
Holstein 1	-0.02	76	-0.56	79
Holstein 2	-0.34	54	0.75	44
Breed average	-0.15	130	-0.09	123
Brown Swiss 1	0.22	64	-0.69	59
Brown Swiss 2	-0.65	40	0.66	34
Breed average	-0.12	104	-0.20	93

[a]A.D.G. = Average daily gain approximately 60 days after calving in pounds.

[b]1 = Farm 1; 2 = Farm 2.

Table 8. Number of cows exposed and number of cows calving for each farm, breed and year class

Breed of cow	Farm 1							
	1968		1969		1970		Total	
	Exposed	Calving	Exposed	Calving	Exposed	Calving	Exposed	Calving
Angus	100	56	100	77	90	67	290	200
Hereford	100	71	99	71	84	49	283	191
Holstein	100	82	98	80	94	65	292	227
Brown Swiss	100	68	99	59	72	35	271	162
Total	400	277	396	287	340	216	1,136	780

Farm 2								Grand Totals	
1968		1969		1970		Total			
Exposed	Calving	Exposed	Calving	Exposed	Calving	Exposed	Calving	Exposed	Calving
100	41	100	53	76	47	276	141	566	341
100	47	100	51	68	38	268	136	551	327
100	62	99	47	75	30	274	139	566	366
100	43	99	36	68	28	267	107	538	269
400	193	398	187	287	143	1,085	523	2,221	1,303

METHODS OF ANALYSIS

In the analysis of these data, different techniques were involved. First, the analysis of proportion, the success or failure of reproduction, was used. Second, linear models were fitted by least-squares to the reproductive traits, using factors that could influence the variables. The significance of the factors was determined by an F-test. Constant estimates were obtained.

Cochran (1954) discusses the appropriate analysis of data based on proportions. From a contingency table, a χ^2 analysis can be carried out. The quantity X^2 in the equality (1)

$$X^2 = \frac{\sum\sum\sum_{ijk} n_{ijk} \, (p_{ijk} - p_{...})^2}{(p_{...})\,(1-p_{...})} \tag{1}$$

is considered by Cochran as a weighted sum of squares of the deviations of the individual proportion of successes (p_{ijk}) from the general mean ($p_{...}$) with weights $n_{ijk}/(p_{...})$. Hence, $\chi^2_{(n-1)d.f.}$ may be partitioned into independent components in the analysis of variance as is shown in the partition of the sums of squares in Table 12. By this partition of the χ^2 sums of squares, the general hypothesis that $p_{ijk} = p_{...}$ is tested by a χ^2 or F-test.

Since the primary interest in this study is centered on the analysis of sources of variation and constant estimates of effects defined in the models, a method of analysis which fulfills this condition is required. The calving distributions of farm 1 for the years 1968, 1969 and 1970 are shown in Figures 2, 4 and 6. The distributions of the first service dates for the same farm and years are shown in Figures 3, 5 and 7. As expected from the data under study, calving date distribution approaches normality, but distribution of first service shows a wide departure from normality. Gestation length and calving interval are expected to follow a normal distribution, but the other two (postpartum interval and conception length) did not follow the normal distribution. Thus, a general method to analyze these data, which will not be biased by nonnormality, is required. The effect of nonnormality and inequality of variance on the different statistical tests is discussed by Scheffé (1959). Statistical methods have been called "robust" if the inferences are not seriously invalidated by the violation of such assumptions. The F-test has the property of robustness against nonnormality and inequality of variance.

A general least-squares analysis as described by Harvey (1960) fulfills the requirements. A classification model of the form

$$y = XB + e \tag{2}$$

describes the biological situation for any of the reproductive traits under study, where y represents the column vector for the dependent variable; B is a column vector of all fixed

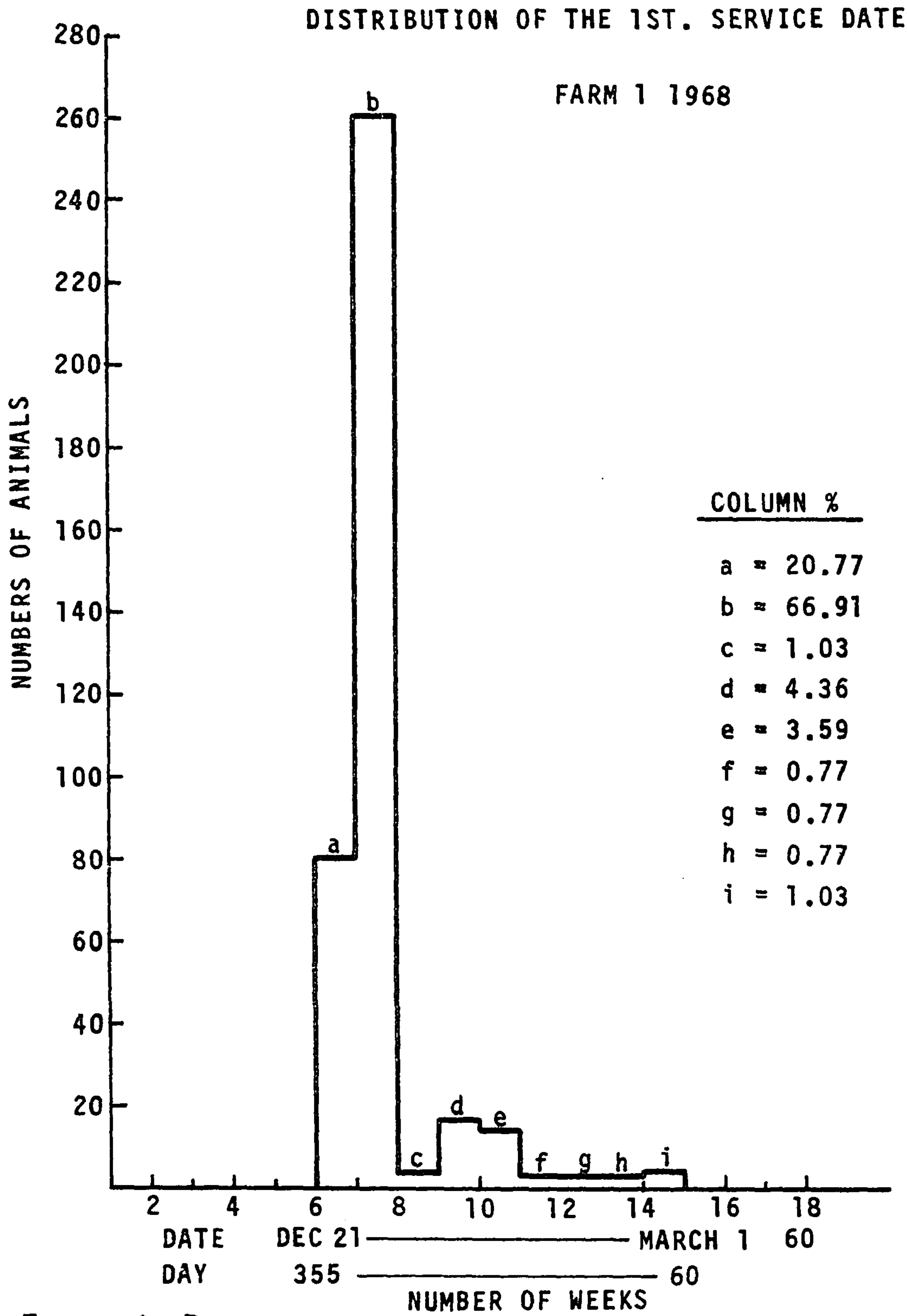

FIGURE 2. DISTRIBUTION OF THE FIRST SERVICE DATE 1968.

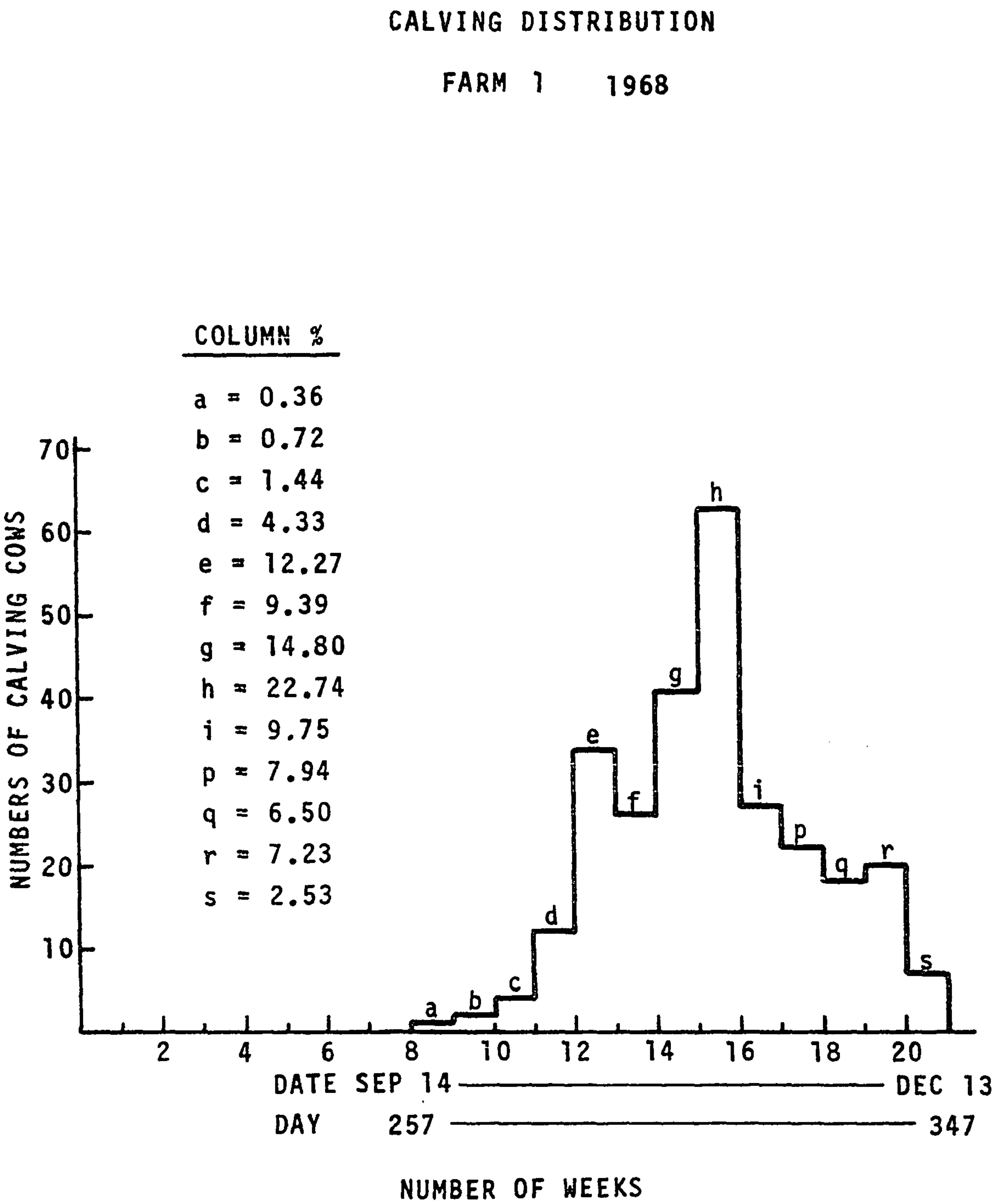

FIGURE 3. CALVING DISTRIBUTION 1968.

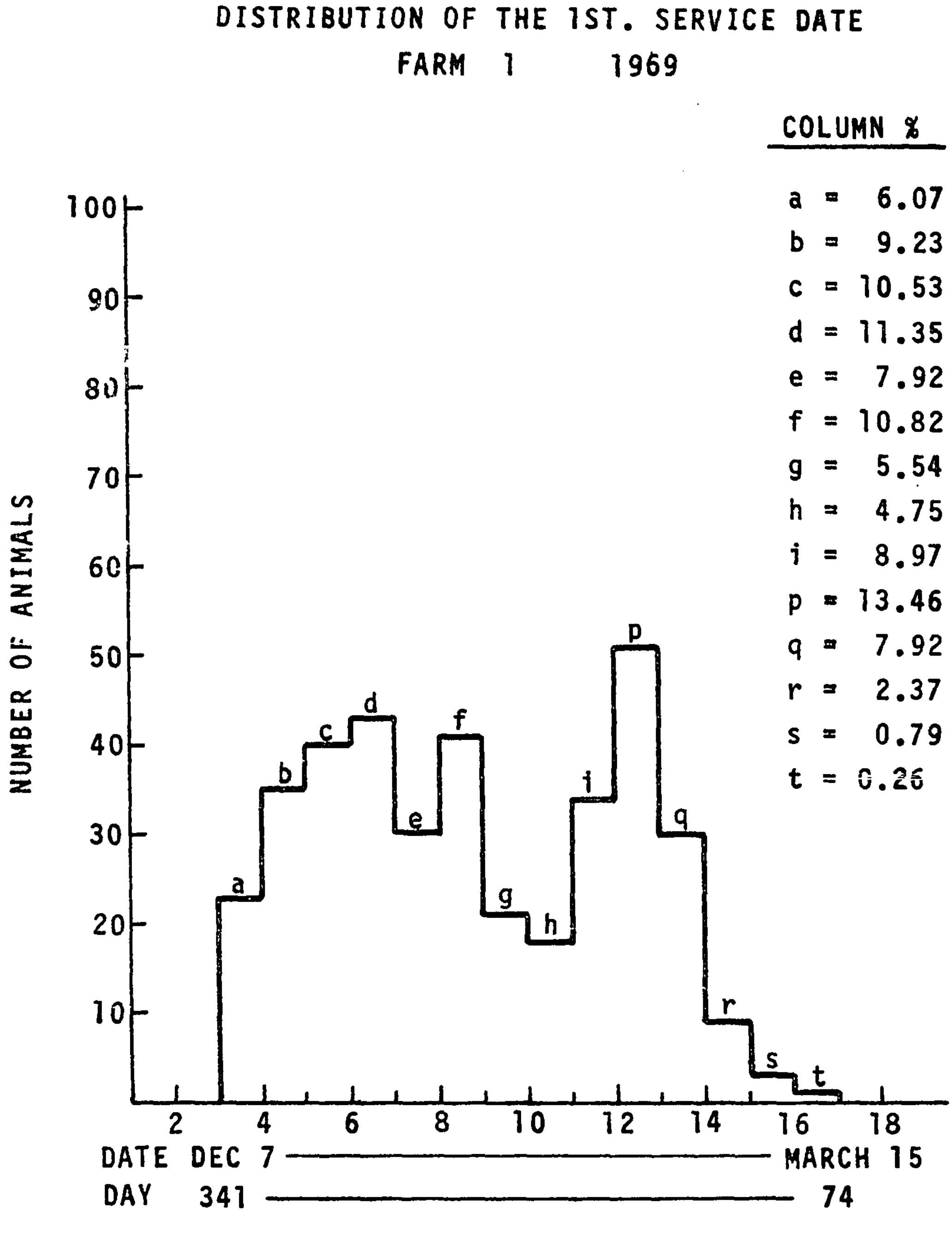

FIGURE 4. DISTRIBUTION OF THE FIRST SERVICE DATE 1969.

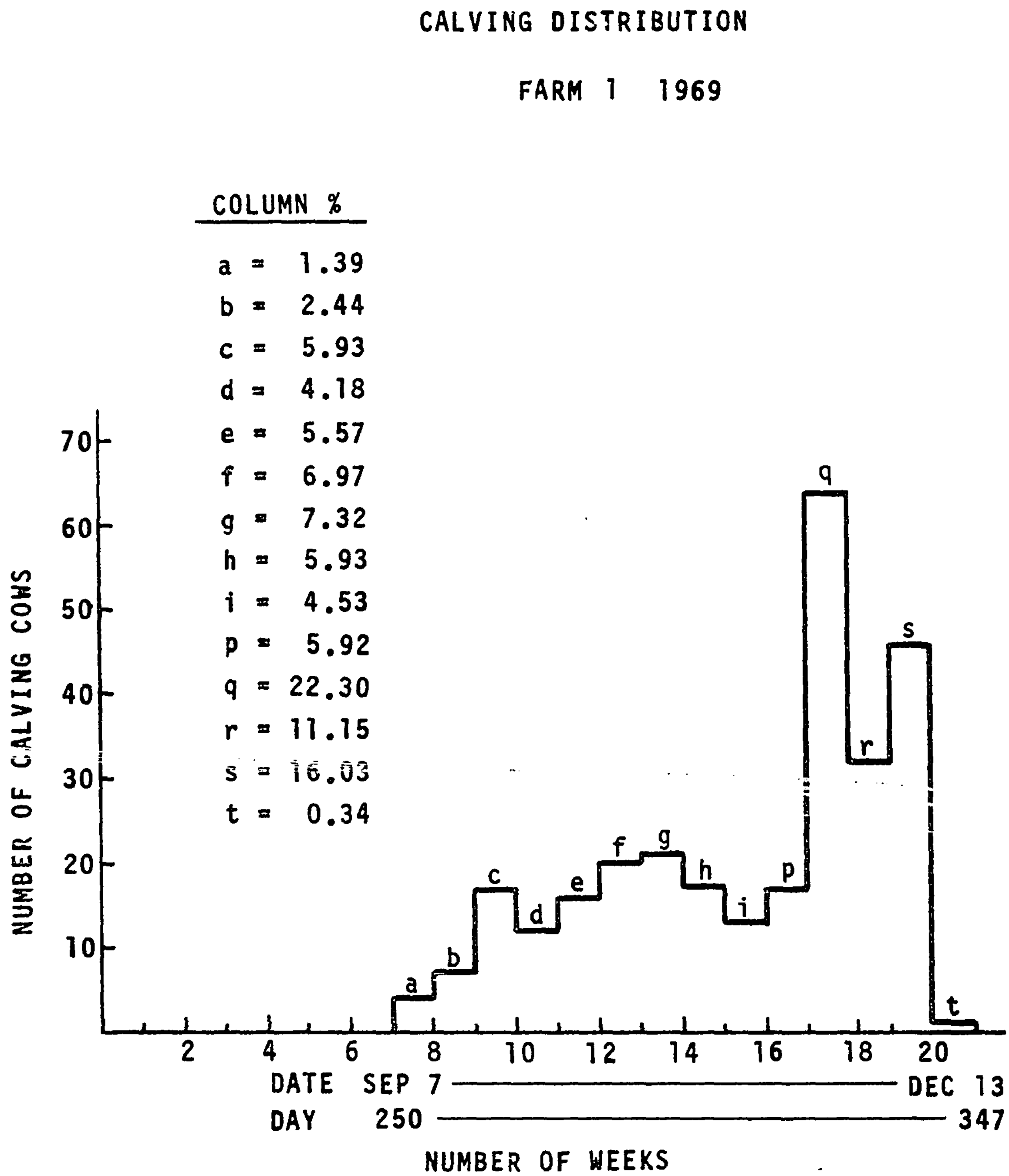

FIGURE 5. CALVING DISTRIBUTION 1969.

DISTRIBUTION OF THE 1ST. SERVICE DATE

FARM 1 1970

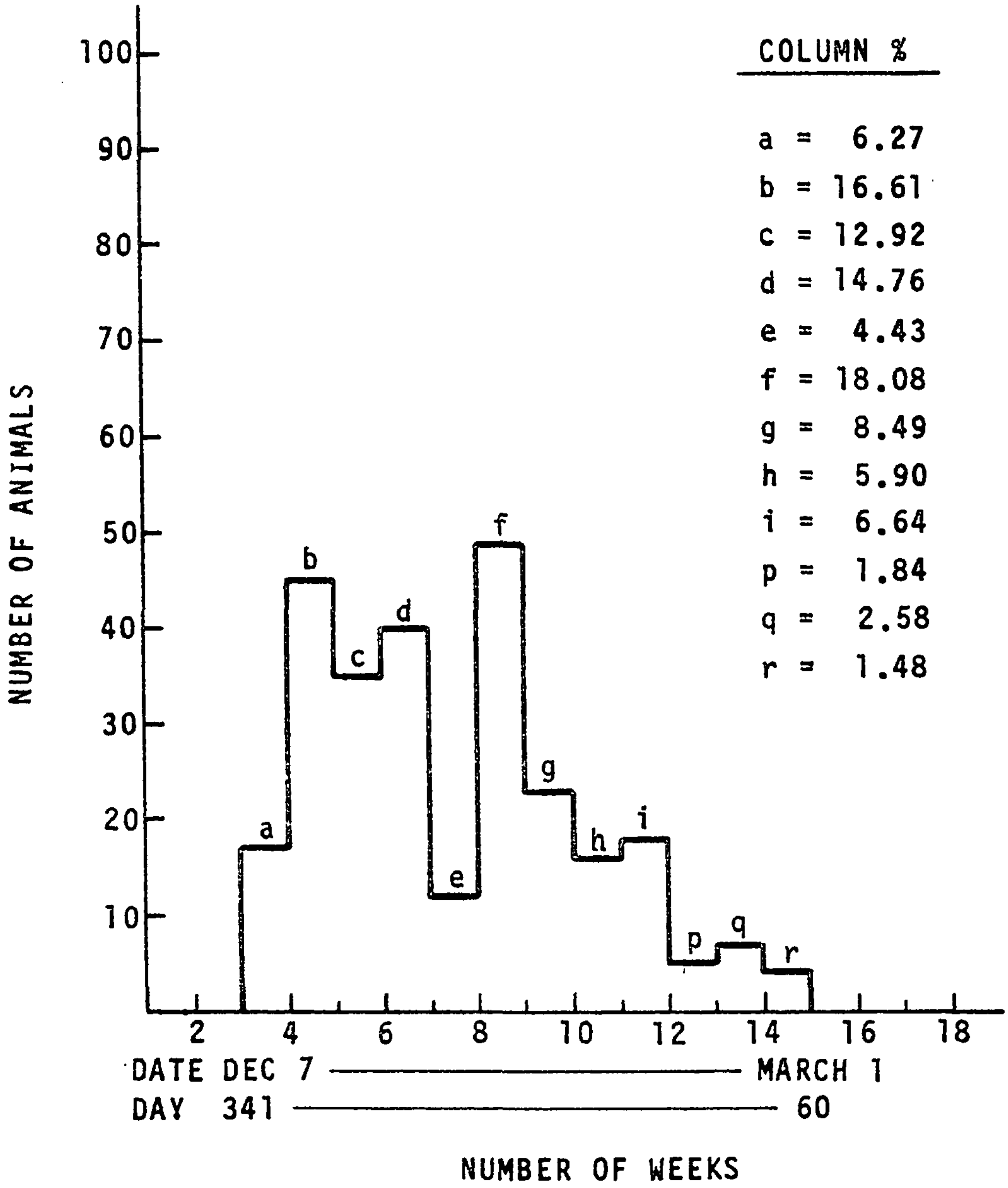

FIGURE 6. DISTRIBUTION OF THE FIRST SERVICE DATE 1970.

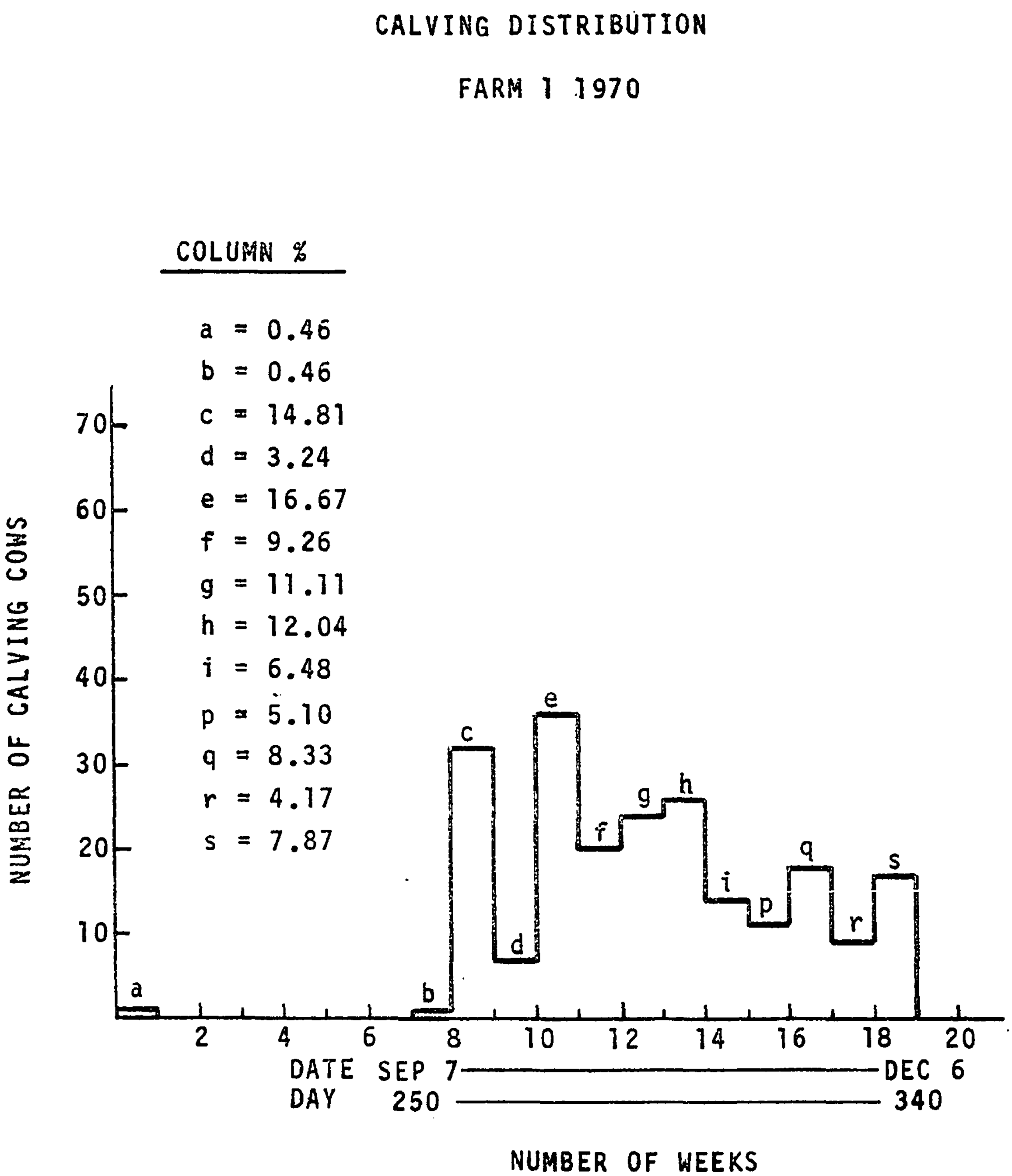

FIGURE 7. CALVING DISTRIBUTION 1970.

effects including possible interactions and regressions; X is the corresponding design matrix of zeros and ones and the continuous independent variables, and e is a column vector of random effects associated with the dependent variable y. All effects in the model, except the random deviations, are considered fixed in the statistical sense. Using least-squares theory, a system of equations called "normal equations" was developed. The solution of these equations, in terms of the effects in the model, minimize the error sum of squares. The set of normal equations is

$$X'XB = X'y.$$

The normal equations for the model do not have a unique solution, because of the dependency of rows and columns in the X matrix. Harvey (1960) has suggested restrictions on the constant estimates which lead to a reduced X matrix (X_R). An appropriate set of restrictions is that the sum of all constants of a factor should sum to zero. In doing so, a unique solution of the B's is achieved, where any b_i obtained in this set is the best linear unbiased estimator. Now the complete set of reduced least-squares equations is

$$X_R'X_RB = X_R'\,y$$

or

$$C_RB = Y_R$$

where

$$C_R = X_R'X_R$$

and

$$Y_R = X_R' \, y.$$

The estimation of $\hat{B}$ is given by

$$\hat{B}_R = C_R^{-1} Y_R$$

where C_R^{-1} is the inverse of $X_R'X_R$.

The reduction in the sum of squares due to fitting the constants for a particular factor is of the general form

$$\hat{B}_i' Z^{-1} \hat{B}_i \qquad (3)$$

where $\hat{B}_i'$ is a row vector of the constant estimates for the i^{th} factor; Z^{-1} is the inverse of the square symmetrical segment of the inverse of C_R which corresponds by row and column, to the i^{th} factor; and $\hat{B}_i$ is a column vector of the constant estimates for the i^{th} factor.

The total reduction in sum of squares is $\hat{B}_R Y_R$ and the error sum of squares (residual) is given by $y'y - \hat{B}_R Y_R$. Standard errors of the least-squares means are computed from the inverse elements and the standard deviation. The standard error for the i^{th} constant may be obtained from the general form

$$\sqrt{\bar{C}_{R_{ii}} \sigma_e^2}$$

where C_R is an element of the inverse of the reduced normal equations, and σ_e^2 is the error mean square. The subscripts $_{ii}$ refer to the diagonal element of the C matrix corresponding to the i^{th} row and column.

The three degrees of freedom for breed of cow and sires can be broken down into single degrees of freedom orthogonal comparisons. The set of interest chosen was to compare beef versus dairy breeds and the two breeds within each type against each other. Harvey illustrates the procedure to calculate the sum of squares for such orthogonal comparisons. A transformed inverse matrix called T is defined as T = KZK', where K is a reduced matrix of the coefficients of the orthogonal contrast, Z is defined in equation (3), and K' is the transpose of K. The numerator sum of squares (C_j^2) for testing the significance of a single degree of freedom contrast is obtained from equation (3) in the usual manner. The sum of squares for any contrast is given by C_j^2/T^{jj} where the subscript j in C^2 refers to a chosen contrast and the superscript jj in T, to the diagonal element of the T matrix.

Since conception rate and conception length are recognized to measure the same parameter, conception length was used as a measurement in this study for the following reasons. First, conception rate is expressed as a proportion while conception length is a continuous variable. An important advantage of conception length is that it measures the real number of days needed to conception rather than a chosen service number. A third consideration is that conception rate plus postpartum interval and gestation length does not give the calving interval as conception length does. Thus, no linear and additive relationship holds in this consideration between conception rate and the other reproductive traits under study.

Two kinds of analysis are possible since cows were grouped by number and year of calving.

The objective in Analysis I was to look into the different pattern of the traits observed for cows that calved once, twice or three times and to determine which are the most important sources of variation in reproductive performance. The traits under study were postpartum interval, conception length and gestation length. Since one classification was made based on all possible combinations of years and calvings for the three years under study, we have the structure shown in Table 9.

Table 9. Classification of the data by groups in Analysis I

Years	Number of calvings		
	One	Two	Three
1968	Group 1	Groups 4 and 6	Group 7
1969	Group 2	Groups 4 and 5	Group 7
1970	Group 3	Groups 5 and 6	Group 7

Groups 3 and 6, which represented the cows that calved only once (1970) and twice (1968-70), respectively, were eliminated from the study because they contained too few animals.

Analysis II concerns the reproductive performance of cows that calved at least twice. The traits under study were calving interval, postpartum interval, conception length and gestation length. In the three years under study the combinations which could be obtained are shown in Table 10.

Table 10. Structure of data in Analysis II

Number of Calving intervals	Years of consecutive parturitions		
1	1968-69	1969-70	1968-70
2	1968-69-70		

In this analysis, only cows that have had two or more parturitions in consecutive years were used. As a result, we have the following composition of the groups under study: group 4, calving 1968-9; group 5, calving 1969-70; group 7, calving 1968-9 and 1969-70. The main purpose was to investigate whether there were differences in the traits under study between groups that calved two or three times and to identify the variables which constitute the most important sources of variation. The analysis was carried out within years for the groups which had one calving interval.

Models

For each reproductive trait, except calving interval, which was considered only in Analysis II, a general model was used both in Analysis I or Analysis II. However, since Analysis I dealt with some cows that calved only once, some terms of the general model were omitted. Then the full model was used to investigate the traits on animals that calved at least twice as was defined in Analysis II. The mathematical identity assumed to describe the biology involved in each reproductive trait is expressed in the corresponding models.

Model 1. Calving interval

The model used to describe calving interval was

$$Y_{ijklmopqr} = \mu + G_i + D_j + S_k + F_l + A_m + P_o + T_{ip} + T_{iq} + DF_{jl} + SF_{kl} + b_1Z_1 + b_2Z_2 + b_3Z_3 + b_4Z_4 + e_{ijklmopqr}$$

where

$Y_{ijklmopqr}$ = the calving interval of the r^{th} cow assigned to the i^{th} group (G_i) of the j^{th} breed of cow (D_j), which calved by the k^{th} breed of bull (S_k) on the l^{th} farm (F_l) given the m^{th} assistance (A_m), calved in the o^{th}

calving period (P_o), treated with p^{th} treatment within groups for the first parturition (T_{ip}) and the q^{th} treatment within groups in the next parturition (T_{iq}). The effects of the model are

μ = the overall mean,

G_i = the effect common to all cows of the i^{th} group,

D_j = the effect common to all cows of the j^{th} breed of cow,

S_k = the effect common to all cows bred by a bull of the k^{th} breed,

F_l = the effect common to all cows of the l^{th} farm,

A_m = the effect common to all cows which received the m^{th} assistance at first parturition,

P_o = the effect common to all cows calving in the o^{th} calving period at first parturition,

T_{ip} = an effect common to all cows which received the p^{th} treatment within the i^{th} group at first parturition,

T_{iq} = an effect common to all cows which received the q^{th} treatment within the i^{th} group in the next parturition,

DF_{jl} = an interaction effect of the j^{th} breed of cow with l^{th} farm,

SF_{kl} = an interaction effect of the k^{th} breed of bull with the l^{th} farm,

b_1 = the partial regression coefficient of calving interval on first calf birth weight,

Z_1 = the first birth weight of the calf by the cow less the average birth weight,

b_2 = the partial regression coefficient of calving interval on the next calf birth weight,

Z_2 = the birth weight of the next calf by the cow less the average birth weight,

b_3 = the partial regression coefficient of calving interval on precalving average daily gain,

Z_3 = the precalving average daily gain weight of the cow less the average precalving average daily gain of all cows,

b_4 = the partial regression coefficient of calving interval on postcalving average daily gain,

Z_4 = the postcalving average daily gain of the cow less the average postcalving average daily gain of all cows, and

$e_{ijklmnopqr}$ = a random deviation associated with the calving interval of a particular cow.

The first and next calf or parturition refers to the order of the events in sequence of time. Only one calving interval was analyzed at the same time from the different groups. Thus, in essence, in analyzing groups 7 and 5, cows with different parities were compared and in analyzing groups 7 and 4, the comparison was between cows with the same parity within a defined period of time.

The models to explain the different components of calving interval were as follows.

Model 2. Postpartum interval

The model used to describe postpartum interval was

$$Y_{ijklmnopq} = \mu + G_i + D_j + S_k + F_l + A_m + M_n + P_o + T_{ip} + DS_{jk} + DF_{jl} + SF_{kl} + b_1Z_1 + b_2Z_2 + b_3Z_3 + e_{ijklmnopq}$$

where

$Y_{ijklmnopq}$ = the postpartum interval of the q^{th} cow assigned to the i^{th} group (G_i) of the j^{th} breed of cow (D_j), which calved by the k^{th} breed of bull (S_k) on the l^{th} farm (F_l) given the m^{th} assistance (A_m) to calve the n^{th} sex of calf (M_n) during the o^{th} calving period (P_o) on the p^{th} treatment within group (T_{ip}). The effects of the model are

μ = the overall mean,

G_i = the effect common to all cows of the i^{th} group,

D_j = the effect common to all cows of the j^{th} breed of cow,

S_k = the effect common to all cows bred by a bull of the

k^{th} breed,

F_l = the effect common to all cows of the l^{th} farm,

A_m = the effect common to all cows which received the m^{th} assistance at parturition,

M_n = the effect common of the n^{th} sex of calf,

P_o = the effect common to all cows calving in the o^{th} calving period,

T_{ip} = an effect common to all cows which received the p^{th} treatment within the i^{th} group,

DS_{jk} = an interaction effect of the j^{th} breed of cow with k^{th} breed of bull,

DF_{jl} = an interaction effect of the j^{th} breed of cow with l^{th} farm,

SF_{kl} = an interaction effect of the k^{th} breed of bull with l^{th} farm,

b_1 = the partial regression coefficient of postpartum interval on calf birth weight,

Z_1 = the birth weight of the calf by the cow less the average birth weight,

b_2 = the partial regression coefficient of postpartum interval on precalving average daily gain,

Z_2 = the precalving average daily gain of the cow less the average precalving average daily gain of all cows,

b_3 = the partial regression coefficient of postpartum interval on postcalving average daily gain,

Z_3 = the postcalving average daily gain of the cow less the average postcalving average daily gain of all cows, and

$e_{ijklmnopq}$ = a random deviation associated with the postpartum interval of a particular cow.

Model 3. Conception length

The model used to describe conception length was

$$Y_{ijklmnpq} = \mu + G_i + D_j + S_k + F_l + A_m + P_n + T_{ip} + DF_{jl} + SF_{kl} + b_1Z_1 + b_2Z_2 + b_3Z_3 + e_{ijklmnpq}$$

where

$Y_{ijklmnpq}$ = the conception length of the q^{th} cow assigned to the i^{th} group (G_i) of the j^{th} breed of cow (D_j), which raise a calf sired by the k^{th} breed of bull (S_k) on the l^{th} farm (F_l) given the m^{th} assistance (A_m) in the n^{th} calving period (P_n) and treated with the p^{th} treatment within the i^{th} group (T_{ip}). The effects of the model are

μ = the overall mean,

G_i = the effect common to all cows of the i^{th} group,

D_j = the effect common to all cows of the j^{th} breed of cow,

S_k = the effect common to all raisen calves sired by a bull from the k^{th} breed,

F_l = the effect common to all cows of the l^{th} farm,

A_m = the effect common to all cows which received the m^{th} assistance at parturition,

P_n = the effect common to all cows calving in the n^{th} calving period,

T_{ip} = an effect common to all cows which received the p^{th} treatment within the i^{th} group,

DF_{jl} = an interaction effect of the j^{th} breed of cow with l^{th} farm,

SF_{kl} = an interaction effect of the k^{th} breed of bull with l^{th} farm,

b_1 = the partial regression coefficient of conception length on calf birth weight,

Z_1 = the birth weight of the calf by the cow less the average birth weight,

b_2 = the partial regression coefficient of conception length on precalving average daily gain,

Z_2 = the precalving average daily gain of the cow less the average precalving average daily gain of all cows,

b_3 = the partial regression coefficient of conception length on postcalving average daily gain,

Z_3 = the postcalving average daily gain of the cow less the average postcalving average daily gain of all cows, and

$e_{ijklmnpq}$ = a random deviation associated with the conception length of a particular cow.

<u>Model 4. Gestation length</u>

The model used to describe gestation length was

$$Y_{ijklmnpq} = \mu + G_i + D_j + S_k + F_l + A_m + M_n + T_{ip} + DS_{jk} + DF_{jl} + SF_{kl} + b_1Z_1 + b_2Z_2 + b_3Z_3 + e_{ijklmnpq}$$

where

$Y_{ijklmnpq}$ = the gestation length of the q^{th} cow assigned to the i^{th} group (G_i) of the j^{th} breed of cow (D_j), which was bred to the k^{th} breed of bull (S_k) on the l^{th} farm (F_l) given the m^{th} assistance (A_m) to calve the n^{th} sex of calf (M_n) and treated with the p^{th} treatment within group (T_{ip}). The effects of the model are

μ = the overall mean,

G_i = the effect common to all cows of the i^{th} group,

D_j = the effect common to all cows of the j^{th} breed of cow,

S_k = the effect common to all cows bred by a bull of the k^{th} breed,

F_l = the effect common to all cows of the l^{th} farm,

A_m = the effect common to all cows which received the n^{th} assistance at parturition,

M_n = the effect common of the n^{th} sex of calf,

T_{ip} = an effect common to all cows which received the p^{th} treatment within the i^{th} group,

DS_{jk} = an interaction effect of the j^{th} breed of cow with k^{th} breed of bull,

DF_{jl} = an interaction effect of the j^{th} breed of cow with l^{th} farm,

SF_{kl} = an interaction effect of the k^{th} breed of bull with l^{th} farm,

b_1 = the partial regression coefficient of gestation length on calf birth weight,

Z_1 = the birth weight of the calf by the cow less the average birth weight,

b_2 = the partial regression coefficient of gestation length on precalving average daily gain,

Z_2 = the precalving average daily gain of the cow less the average precalving average daily gain of all cows,

b_3 = the partial regression coefficient of gestation length on postcalving average daily gain,

Z_3 = the postcalving average daily gain of the cow less the average postcalving average daily gain of all cows, and

$e_{ijklmnpq}$ = a random deviation associated with the gestation of a particular cow.

An analysis of variance was performed for each analysis and trait under study. F-tests from the analysis of variance table indicate whether the mean differences found for particular effects could have arisen solely by chance or not.

All possible simple interclass correlations between calving interval and its three components; postpartum interval, conception length, and gestation length were computed. The computation was performed using the same data used in Analysis II. Standarized partial regression coefficients of calving interval on its components were obtained using the interclass correlations. Since the sum of the three reproductive traits equals calving interval, use of the partial regression coefficients to determine the relative importance of the three traits on calving interval is possible.

RESULTS AND DISCUSSION

Analysis of Proportions

In Table 11, the number of cows calving is expressed as a percentage of the total exposed for each farm-breed-year subclass. These data were used to assess the importance of breed of cow, farm and year on reproductive performance.

An analysis of variance for the proportion of cows calving by breeds, farm, years and their interactions was performed according to a procedure described by Cochran (1954). The cows were randomly assigned to farm initially. The results are presented in Table 12. The three-way interaction, breed x farm x year, was used as the error term for the F-tests. The χ^2 probability indicating significance under the null hypothesis ($p_{ijk} = p_{...}$) was in full agreement with the F-test. Breeds, farms, and the interaction of breeds with years were highly significant sources of variation. The effect of management on the farms throughout the years under study influenced reproductive performance. The difference between farm 1 and 2 was 20.5% (257 calves) in favor of farm 1. This can be explained partly by the level of nutrition (Mason, 1966; Cundiff and Gregory, 1968; Pearson and McDowell, 1968 and BreDahl, 1970) but principally by the management system during the fertile cycle of the cow (Chapman and Casida, 1935; Casida *et al.*, 1968; McDowell *et al.*, 1970).

Table 11. Percentage of cows calving for each farm, breed and year class

Breeds	Farm 1 1968	Farm 1 1969	Farm 1 1970	Farm 1 Totals	Farm 2 1968	Farm 2 1969	Farm 2 1970	Farm 2 Totals	Grand Totals
Angus	56.00	77.00	74.44	68.97	41.00	53.00	61.84	51.09	60.25
Hereford	71.00	71.72	58.33	67.49	47.00	51.00	55.88	50.75	59.35
Holstein	82.00	81.63	69.14	77.74	62.00	47.47	40.00	50.73	64.66
Brown Swiss	68.00	59.60	48.61	59.78	43.00	36.36	41.17	40.07	50.00
Totals	69.25	72.47	63.53	68.66	48.25	46.98	49.83	48.20	58.67

Table 12. The analysis of variance for proportion of cows calving for each breed, farm and year class

Sources	d.f.	Sum of squares (S.S.)	S.S.	$\chi^{2\,a}$	P^b	F^c
Breeds	3	$\Sigma n_{i..}(p_{i..}-p_{...})^2$	3.5490	14.6637**	<0.005	6.68**
Farms	1	$\Sigma n_{.j.}(p_{.j.}-p_{...})^2$	13.4059	55.3906**	<0.005	75.77**
Breeds x farms	3	$\Sigma n_{ij.}(p_{ij.}-p_{i..}-p_{.j.}+p_{...})^2$	0.5347	2.2095	≃0.500	1.00
Years	2	$\Sigma n_{..k}(p_{..k}-p_{...})^2$	0.1297	0.5361	≃0.975	0.36
Breeds x years	6	$\Sigma n_{i.k}(p_{i.k}-p_{i..}-p_{..k}+p_{...})^2$	4.3707	18.0587**	0.001	4.11**
Farms x years	2	$\Sigma n_{.jk}(p_{.jk}-p_{.j.}-p_{..k}+p_{...})^2$	0.7195	2.9730	0.250	2.03
Breeds x farms x years	6	$\Sigma n_{ijk}(p_{ijk}-p_{ij.}-p_{i.k}-p_{.jk}+p_{i..}+p_{.j.}+p_{..k}-p_{...})^2$	1.0542	4.3860	0.750	
Total	23	$\Sigma n_{ijk}(p_{ijk}-p_{...})^2$	24.5994			

$^a\chi^2 = S.S./(p_{...})(1-p_{...})$.

^bP = Probability level.

^cF = F-test.

$^{**}P < 0.01$.

There were important differences in the performance of the four breeds under study. The rank of the breeds (Table 8), for the total number of calves through the three years, from greatest to smallest, was Holstein, Angus, Hereford and Brown Swiss. The differences amounted to as much as 14.7% (103 calves) over the years between the highest (Holstein) and the lowest ranked breed (Brown Swiss). Everett et al. (1966) reported superior fertility among Holstein cows compared with Guernsey animals. There have been no comparisons published of the four breeds kept together for beef production, but it is reasonable to suppose that some divergence exists in reproductive performance among them. In spite of the high intensity of natural and artificial selection among the presently common breeds, it is not safe to assume that selection acted upon the same sets of genes responsible for reproductive performance in each case.

The interaction of breed by year being statistically highly significant means that the breeds did not have the same relative reproductive performance each year or that the effect of years on the breeds might change their relative performance. In other words, in evaluating breeds, it should be specified in which year the records of reproductive performances were made. In effect, the average reproductive performance (in percent of calves), of dairy cattle declined from 63.8% to 51.1%, while beef cattle increased from 53.8%

to 63.2%. Holstein cows showed a decrease from 72.0% to 56.2%. Angus cows increased from 48.5% to 71.7% for the same years. The decreasing reproductive performance of dairy cows may be a response of dairy cattle to a beef system with a breeding and calving season as well as to the suckling effect (Lauderdale et al., 1968 and Saiduddin et al., 1968). Another important fact was that more dairy cows calved in the 1969 calving season. Breed of cow is partially confounded with calving period in 1969 and 1970. This was due to more dairy cattle being rebred after weaning in 1969 than the beef breeds. A higher proportion of Holstein and Brown Swiss cows was treated with Azium to conclude gestation than Angus and Hereford cows. This behavior of dairy animals generated a partial confounding effect of breed with treatment within years. In Analyses I and II, these effects are examined.

The ranking of the years from best to poorest was 1969, 1968 and 1970 with 59.7%, 58.8% and 55.7% respectively. In the first year (1968), heifers were inseminated after synchronization with MGA. Synchronization procedures with synthetic steroids have been reported to lower conception rate at first service but reproductive performance is reported to be back to normal at second service (Anderson et al., 1962 and Zimbelman and Smith, 1966). With a 60-day breeding season, normal animals had the opportunity to show at least two heats. The low conception rate, during the first synchronized estrus is probably not all due to lowered fertility from the treatment. Management system and environmental conditions seem likely to be responsible (VanDemark, 1954; Casida *et al.*, 1968 and McDowell *et al.*, 1970). This is supported by the performance of 1970. In addition to this, age of dam and the intensity of selection practiced was confounded with the breed x year effect and it was not possible to estimate these sources of variation independently. Furthermore, culling of cows on a pregnancy exam in the spring of 1969 and 1970 was not uniform among breeds and farm. More cows were culled on farm 2 and among breeds, more Brown Swiss were culled than other breeds.

A valid conclusion from Table 12 is that breeds differ significantly with respect of their reproductive performance, regardless of level of nutrition and husbandry practices. But the most important source of variation is the management system under which the cows performed. The breeding season is short in beef production and therefore management with regard to the detection of heat, accuracy of service, techniques and general management practices during the fertile cycle of the cow must be of the highest order if profit from the industry is to be maximized (VanDemark and Salisbury, 1950; VanDemark, 1954 and Casida *et al.*, 1968). In view of this, perhaps a higher estimate of repeatability for reproductive traits might be obtained if corrections could be made for some environmental factors (Olds and Seath, 1953 and Johnson *et al.*, 1964).

Analyses of Reproductive Traits

Preliminary analyses were carried out in order to investigate every factor which could influence every reproductive trait. A problem of lack of independence between the factors in the model arose in doing so. When estimating constants for the different factors involved, independence and additivity are the critical assumptions. The results for calving interval, postpartum interval, conception length and gestation length are presented in Tables 13 and 14 for Analysis I and Tables 19 and 20 for Analysis II. Estimates of the constants and their standard errors appear in Tables 15 and 16 for Analysis I and Tables 21 and 22 for Analysis II. The analyses for orthogonal comparisons are given in Tables 17, 18, 23 and 24. In Analyses I and II, constant estimates for each factor in the models were fitted simultaneously.

The objective in Analysis I was to look into the different patterns of the traits observed for cows that calved once, twice or three times and to determine which factors are the most important sources of variation in reproductive performance and might help explain the reproductive performance indicated in Table 8. Groups of cows as described in the source of data section were compared to investigate which factors, defined in the models for the three reproductive traits (postpartum interval, conception length and gestation length), were responsible for low or high reproductive performance among the four breeds of cows.

Analysis II concerns the reproductive performance of cows that calved at least twice. The main purpose was to investigate differences in calving interval and how the components of calving interval influence it. Analyses were performed using groups of cows that calved two or three times. The importance of the various factors leading to differences in the reproductive performance of the breeds was examined.

Analysis I

Reproductive records of cows calving in 1968 or 1969 were used in Analysis I. However, not all cows were included in the analysis. In 1968, group 6 was not considered for the reasons explained in the source of data section. In 1970, groups 3 and 6 were eliminated from the analysis for the same reasons. The 1968 analysis was performed on group 1, 4 and 7 which represent cows calved once, twice and three times respectively. In 1969, no elimination of any group was practiced. Group 2, 4, 5 and 7 constituted the 1969 analysis. In 1970, since groups 3 and 6 were not involved in the analyses, analyses were performed using groups 5 and 7 which are comparisons between cows with one and two calving intervals which will be discussed in Analysis II. Thus, only 1968 and 1969 calvings were considered in Analysis I.

The objective of Analysis I was to examine the different patterns of postpartum interval, conception length and gestation length in a year analysis for cows which had different numbers of calvings. Also, the important sources of variation influencing the reproductive measures were considered. These sources were compared with the important sources found in cows with 2 or 3 calvings. Such evaluation can begin to explain the breed differences observed in the calving percentages.

Postpartum interval

Postpartum interval is defined as the number of days which a cow remains unbred after parturition. The variation is due both to difference between individuals and to the particular management system, since the breeding season was fixed in the data. During the postpartum interval, the first postpartum ovulation usually occurs in the absence of behavioral estrus and on the average about 30 days after calving in the dairy cow and about 40 days after parturition in the beef cow (Casida and Wisnicky, 1950; Graves *et al.*, 1968 and Hafez, 1968). There exists considerable individual variation in the time of first ovulation in both beef and dairy cattle. Ovulation will occur within a few days after calving in some females, but not until several months afterwards in others (Hafez, 1968 and Wagner and Hansel, 1969). Therefore, the first recorded service does not mean the first ovulation even if there is not any intentional delay in breeding. Management is reported by Chapman and Casida (1935), Carman (1955) and Tudorascu (1968) to contribute more than any other source of variation. Since reproductive performance in this study was measured on animals within a definite period of time and selection was practiced, the value of postpartum interval might be lower than would be true in a population without these restrictions. However, literature mainly reported from dairy cattle by Smith and Legates (1962), Everett et al. (1966), Auran (1970) had nearly the same structure.

A least-squares analysis was performed using model 2. The analysis for the year 1968 is presented in Table 13 and for the year 1969 in Table 14. Constant estimates are given in Tables 15 and 16 while orthogonal comparisons are presented in Tables 17 and 18 for the years 1968 and 1969 respectively. The overall mean and standard deviations for 1968 and 1969 were 86.3 ± 23.4 and 73.2 ± 25.5 days respectively. The coefficients of variation for these figures were 27.1% for 1968 and 34.8% for 1969. The smaller coefficient of variation for 1968 can be explained by a shorter breeding season than in 1969. The more expanded calving period in 1969 is clearly apparent in Figure 4 for the first breeding date and Figure 5 for the calving distribution when compared with Figures 2 and 3 for 1968.

Farms and calving period were the most important sources of variation in postpartum interval. Cows on farm 1 had consistently shorter intervals than those on farm 2; the differences were 17.7 and 10.6 days for 1968 and 1969 respectively. It seems probable that this difference is due not to the location of the farms so much as to the management thereon, according to the work of Olds and Seath (1950), Carman (1955), Branton *et al*. (1956), Maijala (1964) and Everett *et al*. (1966). It would appear that the standard of nutrition, care of the cows, and estrous detection may have been more accurate on farm 1 than on farm 2. Tables 6 and 7 indicate average daily gain either pre or post calving is higher on farm 1 than on farm 2. BreDahl (1970) stated that the appearance of the cows indicated that the level of nutrition was higher at farm 1. Thus, level of nutrition was probably one factor. A preliminary analysis of the length and variability of heat (compared on basis of the same length of estrous cycle) showed that cows on farm 1 had less variability suggesting that heat was detected more accurately on farm 1.

Most of the cows calved within the coded calving period 5, 6 and 7 (299$^{\underline{th}}$ to 340$^{\underline{th}}$ day of the year). A difference in postpartum interval of 52.0 days was found between cows calving in period 3 and cows calving in period 8 for 1968 year. In 1969, the difference in postpartum interval was 62.7 days between cows calved in calving period 2 and cows calving in period 8. Breeding seasons after parturition started on a fixed date, the third week of December. Cows that calved late in the season had the opportunity to be bred earlier than cows calving early in the season. However, cows that calved early did not always continue to do so in subsequent years. All other factors studied are adjusted for calving period since the constants were fitted simultaneously.

Breed of cow and group were highly significant sources of variation in postpartum interval for year 1968, but not in 1969. The shortest postpartum interval after first calving in 1968 (Tables 13 and 14) was that of the Hereford cows, 13.3 days shorter than that of the Holstein cows which had the longest one (100.1 days). No such difference was shown in 1969 where the average postpartum interval was 83 days.

Group of cow was an important factor in the variation of postpartum interval only in 1968. Nevertheless, in 1969, cows of group 2 (one calving) differed as much as 8.4 days from cows of group 7 (three calvings). Cows of group 7 had the shortest postpartum interval (Table 15). In general, cows which calved more than once had shorter postpartum intervals. The ranking in increasing order was: first, cows that calved three times (group 7); second, cows that calved twice (groups 4 and 5) and finally, cows that calved once (groups 1 and 2). Since, on the average, the shortest postpartum interval was greater than 60 days (Tables 15 and 16), which is the maximum required by normal nursing cows to show the first heat after calving (Casida and Wisnicky, 1950 and Hafez, 1968), really a shorter postpartum interval exists in favor of the most fertile cows, even though farm and calving period have a major effect.

Since in 1968 the calving season was shorter than in 1969, breed and group of cows had the opportunity to show their effect on postpartum interval. Otherwise, these effects were masked by calving period. Dairy cows have been reported to have longer postpartum intervals than beef cows by Casida and Wisnicky (1950) and Hafez (1968). In the present study, the most fertile cows (3 calves) had the shortest postpartum interval regardless of the breed of dam.

The effects of breed and group of cows were not significant in 1969. This was probably due to the fact that breed and group were partially confounded with calving period and that the calving interval constants contain breed of cow differences. An auxiliary explanation might be found in suckling and cow age effects and their interactions (Lauderdale et al., 1968 and Saiduddin et al., 1968). This latter explanation is supported by the sex effect in the same years.

Sex of the calf shows a significant difference only in the 1968 analysis. Those postpartum intervals which follow the birth of bull calves were 6.0 days longer than those following the birth of heifer calves (Table 15). In 1969, no significant differences were noticed on postpartum interval due to sex of calf. That there was no sex difference can be

Table 13. Mean squares for three reproductive traits of cow calving during 1968 (Groups 1, 4 and 7) - Analysis I

Source[1]	Reproductive traits					
	d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
Group	2	2,419.28**	2	116.89	2	27.19
Breed of cow	3	1,686.29**	3	807.90*	3	372.75**
Breed of sire (1)[a]	3	76.14	---	---	3	94.56**
Farm	1	5,099.93**	1	281.85	1	164.09**
Assistance (1)	1	83.61	---	---	1	17.63
Sex (1)	1	2,542.82**	---	---	1	0.04
Calving period	6	9,953.65**	---	---	---	---

[1]Superscripts used in this table and all subsequent tables indicate:
[a]The number in parenthesis refers to the number of the source in sequence of time; [b]interaction effect; [c]b_1 = the partial regression coefficient of the dependent variable on first calf birth weight; b_3 = the partial regression coefficient of the dependent variable on average precalving weight gain; b_4 = the partial regression coefficient of the dependent variable on average postcalving weight gain.

*P < 0.05.

**P < 0.01.

Table 13. (Continued)

Source[1]	d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
		Reproductive traits				
Breed of cow x breed of sire (1)[b]	9	301.51	---	---	9	28.17
Breed of cow x farm	3	349.73	3	142.86	3	12.54
Breed of sire (1) x farm	3	242.88	---	---	3	2.89
b_1[c]	1	44.34	---	---	1	896.69**
b_3	1	45.56	---	---	1	48.39
b_4	1	1,864.47*	---	---	---	---
Remainder	303	296.46	403	217.45	342	22.00

Table 14. Mean squares for three reproductive traits of cows calving during 1969 (Groups 2, 4, 5 and 7) - Analysis I

Source[1]	Reproductive traits					
	d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
Group	3	358.12	3	2,336.29**	3	75.03
Breed of cow	3	173.48	3	76.34	3	455.39**
Breed of sire (2)	3	431.40	---	---	3	257.43**
Farm	1	15,269.70**	1	1,203.98*	1	574.59**
Assistance (2)	1	0.66	---	---	1	74.00
Sex (2)	1	304.98	---	---	1	117.13*
Calving period	7	6,109.66**	---	---	---	---
Treatment$_{12}$[d]	1	273.67	---	---	1	11.47

[1]Superscripts used in this table and all subsequent tables indicate:
[d]The double subscripts for treatment refer to treatment and group (nested effect); [e]b_2 = the partial regression coefficient of the dependent variable on next calf birth weight.

*P < 0.05.

**P < 0.01.

Table 14. (Continued)

Source[1]	d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
	Reproductive traits					
Treatment_{14}	1	373.26	---	---	1	47.73
Treatment_{15}	1	233.82	---	---	1	2.22
Treatment_{17}	1	3,322.72**	---	---	1	139.09*
Breed of cow x breed of sire (2)[b]	9	275.11	---	---	9	33.99
Breed of cow x farm	3	263.58	3	246.13	3	49.87
Breed of sire (2) x farm	3	249.07	---	---	3	29.41
b_2[e]	1	1,707.78*	---	---	1	2,891.59**
b_3[c]	1	1,037.90	---	---	1	0.00
b_4	1	9.15	---	---	1	56.33
Remainder	341	293.91	403	305.21	376	28.79

Table 15. Constant estimates of main effects and regressions and their standard error for three reproductive traits of cow calving in 1968 (Groups 1, 4 and 7) - Analysis I

Constant[1]	Postpartum interval	Conception length	Gestation length
μ	94.08 ± 2.18	19.13 ± 0.79	282.61 ± 0.29
Group 1[f]	2.03 ± 2.66	0.22 ± 1.32	0.07 ± 0.47
Group 4[g]	3.46 ± 2.85	0.82 ± 1.63	0.46 ± 0.56
Group 7[h]	-5.48 ± 2.47	-1.04 ± 1.14	-0.53 ± 0.42
Breed of cow 1[i]	-0.99 ± 3.20	4.41 ± 1.66	-0.40 ± 0.61
Breed of cow 2	-7.32 ± 2.93	-1.47 ± 1.52	2.57 ± 0.57
Breed of cow 3	5.97 ± 2.70	-2.16 ± 1.33	-2.84 ± 0.53
Breed of cow 4	2.33 ± 3.56	-0.77 ± 1.61	0.66 ± 0.68

[1]Superscripts and subscripts used in this table and all subsequent tables indicate:

[f]cows calving in 1968; [g]cows calving in 1968 and 1969; [h]cows calving in 1968, 1969 and 1970; [i]the digits used refer to breeds where 1 = Angus, 2 = Hereford, 3 = Holstein and 4 = Brown Swiss; [j]the first subscript refers to calving number and the second to assistance (1) or no assistance (0); [k]the digits used refer to calving period, where 2 = cows calving between 257 and 270 days, 3 = cows calving between 271 and 284 days, 4 = cows calving between 285 and 298 days, 5 = cows calving between 299 and 312 days, 6 = cows calving between 313 and 326 days, 7 = cows calving between 327 and 340 days, 8 = cows calving between 341 and 354 days.

Table 15. (Continued)

Constant[1]	Postpartum interval	Conception length	Gestation length
Breed of sire (1)[a] 1[i]	-0.38 ± 3.21	--- ---	0.41 ± 0.57
Breed of sire (1) 2	-0.21 ± 2.76	--- ---	1.08 ± 0.52
Breed of sire (1) 3	1.70 ± 2.94	--- ---	-1.69 ± 0.60
Breed of sire (1) 4	-1.11 ± 2.86	--- ---	0.19 ± 0.54
Farm 1	-5.81 ± 2.24	-0.90 ± 1.01	-0.78 ± 0.33
Farm 2	5.81 ± 2.89	0.90 ± 1.21	0.78 ± 0.47
Assistance $_{10}$[j]	-0.59 ± 2.35	--- ---	0.26 ± 0.37
Assistance $_{11}$	0.59 ± 2.54	--- ---	-0.26 ± 0.44
Sex (1)[a], male	2.98 ± 2.32	--- ---	-0.01 ± 0.36
Sex (1), female	-2.98 ± 2.48	--- ---	0.01 ± 0.41
Calving period 2[k]	17.77 ± 11.06	--- ---	--- ---
Calving period 3	26.23 ± 5.38	--- ---	--- ---
Calving period 4	19.85 ± 2.81	--- ---	--- ---
Calving period 5	-0.17 ± 1.88	--- ---	--- ---
Calving period 6	-14.85 ± 2.35	--- ---	--- ---

Table 15. (Continued)

Constant[1]	Postpartum interval	Conception length	Gestation length
Calving period 7	-23.07 ± 2.39	--- ---	--- ---
Calving period 8	-25.75 ± 5.33	--- ---	--- ---
b_1[c]	-0.05 ± 0.12	--- ---	0.18 ± 0.03
b_3	-0.36 ± 0.93	--- ---	0.26 ± 0.18
b_4	-4.38 ± 1.75	--- ---	--- ---

Table 16. Constant estimates of main effects and regressions and their standard errors for three reproductive traits of cow calving in 1969 (Groups 2, 5, 4 and 7) - Analysis I

Constant[1]	Postpartum interval	Conception length	Gestation length
μ	82.82 ± 2.47	13.72 ± 0.97	279.91 ± 0.52
Group 2^{l}	5.53 ± 4.88	10.11 ± 2.72	1.36 ± 1.07
Group 4^{g}	-0.34 ± 3.27	-5.36 ± 1.90	-1.38 ± 0.78
Group 5^{m}	-2.29 ± 3.42	-1.72 ± 1.74	0.88 ± 0.92
Group 7^{h}	-2.89 ± 2.57	-3.04 ± 1.35	-0.87 ± 0.59
Breed of cow 1^{i}	-1.08 ± 3.17	0.51 ± 1.73	1.99 ± 0.74
Breed of cow 2	0.89 ± 3.19	0.88 ± 1.79	2.96 ± 0.77
Breed of cow 3	-1.50 ± 2.89	-1.03 ± 1.81	-3.39 ± 0.76
Breed of cow 4	1.69 ± 3.25	-0.36 ± 2.01	-1.56 ± 0.84
Breed of sire $(2)^{a}1^{i}$	1.76 ± 3.16	--- ---	1.89 ± 0.78

---

[1] Superscripts and subscripts used in this table and all subsequent tables indicate:

^{l}cows calving in 1969; ^{m}cows calving in 1969 and 1970; ^{n}1 = cows calving between 201 and 256 days; ^{o}the first subscript refers to the number of treatment in sequence of time, the second if the treatment was given (1) or not (0) and the third to the group of the cow.

Table 16. (Continued)

Constant[1]	Postpartum interval	Conception length	Gestation length
Breed of sire (2) 2	1.54 ± 3.00	--- ---	0.48 ± 0.70
Breed of sire (2) 3	0.27 ± 2.95	--- ---	-2.39 ± 0.71
Breed of sire (2) 4	-3.57 ± 2.90	--- ---	0.02 ± 0.73
Farm 1	-8.85 ± 2.49	1.79 ± 1.22	-1.68 ± 0.53
Farm 2	8.85 ± 2.99	-1.79 ± 1.44	1.68 ± 0.73
Assistance$_{20}$[j]	-0.07 ± 2.31	--- ---	0.71 ± 0.41
Assistance$_{21}$	0.07 ± 3.39	--- ---	-0.71 ± 0.87
Sex (2)[a], male	-1.00 ± 2.64	--- ---	-0.58 ± 0.58
Sex (2), female	1.00 ± 2.66	--- ---	0.58 ± 0.60
Calving period 1[n]	33.87 ± 6.36	--- ---	--- ---
Calving period 2[k]	26.87 ± 3.85	--- ---	--- ---
Calving period 3	9.62 ± 3.71	--- ---	--- ---
Calving period 4	6.10 ± 3.63	--- ---	--- ---
Calving period 5	-2.68 ± 3.72	--- ---	--- ---
Calving period 6	-17.96 ± 2.68	--- ---	--- ---

Table 16. (Continued)

Constant[1]	Postpartum interval	Conception length	Gestation length
Calving period 7	-19.93 ± 2.76	--- ---	--- ---
Calving period 8	-35.88 ± 10.62	--- ---	--- ---
$Treatment_{102}$[o]	-4.72 ± 4.11	--- ---	-0.65 ± 1.07
$Treatment_{112}$	4.72 ± 8.86	--- ---	0.65 ± 1.82
$Treatment_{104}$	-2.99 ± 4.20	--- ---	0.86 ± 1.19
$Treatment_{114}$	2.99 ± 4.22	--- ---	-0.86 ± 0.83
$Treatment_{105}$	-2.99 ± 2.77	--- ---	0.25 ± 0.70
$Treatment_{115}$	2.99 ± 6.18	--- ---	-0.25 ± 1.68
$Treatment_{107}$	-6.21 ± 2.79	--- ---	0.95 ± 0.78
$Treatment_{117}$	6.21 ± 3.50	--- ---	-0.95 ± 0.69
b_2[e]	0.24 ± 0.10	--- ---	0.31 ± 0.03
b_3[c]	-1.97 ± 1.05	--- ---	-0.00 ± 0.30
b_4	-0.21 ± 1.18	--- ---	-0.48 ± 0.34

Table 17. Mean squares for orthogonal comparisons among breed of cow and breed of sire on three reproductive traits for cows calving in 1968 (Groups 1, 4 and 7) - Analysis I

Comparisons	Reproductive traits					
	Postpartum interval		Conception length		Gestation length	
	Cow[a]	Sire[b]	Cow	Sire	Cow	Sire
Beef vs. dairy	2,300.58**	18.52	794.38	---	215.73**	156.06**
Angus vs. Hereford	1,405.76*	0.81	1,536.48**	---	324.60**	17.93
Holstein vs. Brown Swiss	291.44	219.43	97.73	---	422.34**	120.22*

[a]Cow = breed of cow.

[b]Sire = breed of sire of the corresponding mating for these traits.

*P < 0.05.

**P < 0.01.

Table 18. Mean squares for orthogonal comparisons among breed of cow and breed of sire on three reproductive traits for cows calving in 1969 (Groups 2, 4, 5 and 7) - Analysis I

Comparisons	Reproductive traits: Postpartum interval		Conception length		Gestation length	
	Cow[a]	Sire[b]	Cow	Sire	Cow	Sire
Beef vs. dairy	1.42	747.75	185.63	---	1,087.63**	422.66**
Angus vs. Hereford	168.48	1.81	7.54	---	43.13	83.73
Holstein vs. Brown Swiss	354.43	583.96	18.97	---	120.69*	248.89**

[a]Cow = breed of cow.

[b]Sire = breed of sire of the corresponding mating for these traits.

*P < 0.05.

**P < 0.01.

explained by the different weaning procedure (180 days vs 90 days) for the second calving. The effect of suckling lengthening the postpartum interval has been reported by Casida *et al*. (1968), Graves *et al*. (1968) and Lauderdale *et al*. (1968). In 1969, with a longer period from birth to weaning, no sex difference would be expected. Breed of sire was supposed to influence postpartum interval by affecting the capacity for milk by the calf but the analysis reveals this is unimportant as a source of variation.

The nested effect of treatment within groups with Azium consistently increased the postpartum interval. Part of this would be due to the fixed breeding and part might be due to a lengthened postpartum interval by the treatment. Although the only difference which was significant statistically was in group 7.

The reduction in sums of squares due to postcalving and precalving average daily weight gain did not show consistently significant reductions on the variability of postpartum interval. The postcalving daily weight gain was significant ($P < 0.05$) in the 1968 analysis, whereas precalving gain appears to be more important than postcalving gain in 1969.

Orthogonal comparisons of interest for breed of dam effects are given in Tables 17 and 18. Beef cattle had significantly shorter postpartum intervals than dairy cattle in 1968 but not in 1969. The average for beef cattle in 1968 was 89.9 compared with an average of 98.2 for dairy animals. Hereford cows showed the shortest postpartum interval with an average of 85.2 days. Thus, it appears that dairy animals under beef management showed longer postpartum intervals than beef cattle, at least in heifers. Part of the lengthened postpartum interval might be due to treatment effect and part to the suckling effect. More dairy cows received Azium than did beef animals, which would cause this difference to become smaller in 1969 when the treatments were used.

The results of both years (1968 and 1969) are conclusive that postpartum interval is largely influenced by environment, mainly management (farm, calving period, treatment, nutrition, etc.). This is in full agreement with the work of Olds and Seath (1950), Carman (1955) and Everett et al. (1966). However, some genetic effects are shown by individuals during the early period of their reproductive lives. Among them, group of cows and breed of cows are the most important. Cows which calved in each of the 3 years had shorter postpartum intervals than any other group throughout the period under study. This reveals a difference among groups of cows calving once, twice or three times. In comparing beef and dairy cattle, some differences in favor of beef cattle for shorter postpartum interval was observed. These differences, nevertheless, are not sustained. More dairy cows received treatment than did beef animals. The lack of breed of cow significance in 1969 may be due in part to calving period being partially confounded with breed of cow since more dairy dams calved later in the calving period than did beef cows.

Conception length

Conception length measures how long it takes for a cow to get a successful service. Since conception length is measured only on animals which actually did conceive, the data refer to a selected set of individuals in a given population. The objective in this study, as far as conception length is concerned, was to determine whether any difference in the number of days from first service to conception exists between cows which calved once, twice or three times. Most of the variation due to voluntary delay of service by management was already taken into account, independently of conception length, by postpartum interval, Thus, the variation in conception length between the different groups of cows is due mainly to the individuals themselves.

Assistance given at parturition, which was found to be highly significant in Analysis II, was not possible to study in Analysis I, because groups of cows calving once were included.

The analysis of conception length was performed using model 3. The overall mean and standard deviation was 18.5 ± 14.8 for 1968 and 12.3 ± 17.8 days for 1969. The coefficients of variation obtained from these figures were 80.4% and 144.7% for 1968 and 1969 years respectively. A larger coefficient of variation in 1969 can be explained by a breeding season 30 days longer than in 1968. Some cows needing more services per conception also became pregnant and, consequently, more variability was observed.

Farm effect was highly signficant in 1969 (Table 14). Thus, it seems that in order for this effect to become manifest and important, a minimum of time is required. This farm effect may result from accuracy of heat detection and all other techniques used to handle cows during the fertile periods. However, much variation remains unexplained.

From the 1968 analysis (Table 13), no difference was observed between cows which calved one, two or three times studied at first parturition. But when more groups of cows were analyzed in 1969, the mean squares due to group increased sufficiently to reach the 1% level of significance. This was clear in 1969 as shown in Table 14. The least-squares means were 23.8, 12.0, 10.7 and 8.4 days for groups 2, 5, 7 and 4 (Table 16). Group 2 and 5 (cows calving for the first time) had the longest conception length whereas group 4 and 7, which are cows calved two consecutive times, had the shortest. Group 2 and 5 had a three-week longer breeding season in 1969 than the cows with a calf at side.

The effect of breed of cow was manifest at the beginning of reproductive performance. Breed of cow showed significant effects in 1968 (Table 13). The least-squares means were 23.5, 18.4, 17.6 and 17.0 days for Angus, Brown Swiss, Hereford and Holstein respectively (Table 15). The superiority of dairy cattle is manifested when analyzing cows which had at least two parturitions (Analysis II), but it is not when the analysis includes cows calved at least once. It suggests that dairy cows which failed to have 2 calvings had troubles in conceiving the first calf. This is supported by the longest conception length of cows calved once regardless of the type of breed of the dam.

The analysis of single degree of freedom comparison among breeds is shown in Tables 17 and 18. Beef cattle had longer conception lengths in every year under study than did dairy cows. A preliminary study of length of estrous cycles showed similar results for beef and dairy cattle, but dairy cows had less variability in the length of estrous cycles. It was observed that under the same management, dairy cows displayed visible signs of estrous, better than beef cows. The largest difference in conception length between type of breed was 3.0 days shorter for dairy cattle. Within type of breed, the maximum difference in conception length was found between Angus and Hereford animals. Angus cows were

5.9 longer in conception length than Herefords. There was no clear difference between the dairy cattle breeds.

Variation in conception length is mostly explained by environmental effects as reported by Buschner et al. (1950), Carman (1955), Everett et al. (1966) and Foote (1970). However, some non-environmental effects were determined as making a significant contribution to the variation. Since not many factors can be included at the same time in a model intended to describe conception length under the assumptions of independence, linearity and additivity, a large error mean square was obtained. A large standard deviation for conception length was reported by Everett et al. (1966).

In this study, groups of cows with one, two or three parturitions performed differently as far as conception length is concerned. The groups with one calving (1 and 2) averaged 21.6 days, while cows with 2 calvings (groups 4 and 5) averaged 13.4 days, and those with three calvings (group 7) averaged 14.4 days.

At the beginning of reproductive life, breed of cow appears to be an important source of variation when beef and dairy cattle are managed for beef purposes.

Number of services per conception for a chosen service appears to be of less value than conception length because the variability in the estrous cycles and the length of these cycles is not considered. Using conception length allows comparisons among cows, breeds, groups, and farms to be made on a trait that includes this variability.

Gestation length

The length of gestation period was reported as nearly constant within breeds by different authors (Livesay and Bee, 1945; Brakel et al., 1952; Everett et al., 1966). Estimators of additive genetic variance ranged from 0 to 0.71 according to Andersen and Plum (1965) and Plum et al. (1965). The fact that literature shows conclusively that gestation length is a heritable factor was used by Plum et al. (1965) to develop an index to select for shorter gestation length. The effect of variation due to the calf and its dam was studied by Jafar et al. (1950). They concluded that the characteristics of the calf are three times more important than those of the dam. There is disagreement in the literature over the influence of the sex of the calf on gestation length. Lasley et al. (1961) found that it did not influence the gestation length of Hereford calves, whereas Rollins et al. (1956) found that Jersey males were carried in uterus 2 days longer than females. BreDahl (1970) analyzed data from the Angus, Hereford, Holstein and Brown Swiss in the present study and reported a longer gestation length for bulls than for heifer calves.

Least-squares analyses were performed using model 4. From Analysis I presented in Tables 13 and 14, the following sources of variation were the most important and consistent over analyses: birth weight of the calf, farm, breed of cow and breed of sire. Treatment to hasten the onset of parturition was another important source of variation, but treatment effect could only be studied in 1969. No treatment was given in 1968. Constant estimates are presented in Tables 15 and 16 for 1968 and 1969 analyses. Orthogonal comparisons among breeds are given in Tables 17 and 18 for 1968 and 1969 respectively.

The overall mean and standard deviation for the years 1968 and 1969 were 282.1 ± 5.3 and 279.6 ± 6.4 days respectively. The coefficient of variation for 1968 was 1.9% while that for 1969 was 2.3%.

Farm was an important source of variation in the analyses (1968 and 1969). Farm 1 had a shorter gestation length. A larger number of dairy cows, especially Holstein, calved at farm 1 than at farm 2 in both years. The use of Azium in 1969 (specially in dairy cattle) was more extensive at farm 1 than at farm 2. This is another factor explaining the differences between farms (Adams, 1969 and Adams and Wagner, 1970).

Birth weight was the most important source of variation in gestation length. A positive covariance between birth weight and gestation length was found and the calves which weighed most had the longest gestation length, regardless of breed of cow, sire, sex, farm and treatment. The regression of birth weight on gestation length ranged from 0.18 to 0.31

pounds per day. This is in keeping with the highly significant regression of birth weight on gestation length of 0.36 pounds per day reported by Rollins et al. (1956). Jafar et al. (1950) also pointed out the importance of the characteristic of the calf on gestation length.

The average least-squares estimators for 1968 and 1969 were 284.1, 282.1, 280.9 and 278.2 for Hereford, Angus, Brown Swiss and Holstein breeds of cow respectively. This is in agreement with results reported by Jafar et al. (1950), Brakel et al. (1952), DeFries et al. (1958) and Konce (1968). BreDahl (1970), reported gestation of 286.2, 284.2, 280.1 and 277.0 days for Brown Swiss, Hereford, Angus and Holstein straightbreds. The difference from BreDahl (1970) in gestation length results is explained by different constraints being placed on the data in this study. Only particular groups of cows were used. BreDahl (1970) used all gestations, while in this study, an animal had to have complete reproductive data.

The effect of Azium was an important factor in shortening gestation length of the breeds. Thirty-three percent of the Hereford calving cows received treatment, 35% of the Angus, 43% of the Brown Swiss, and 51% of the Holstein during 1969. In 1970, 51% of the Hereford cows received Azium or Flucort, 55% of the Angus, 49% of the Brown Swiss and 65% of the Holstein. The different percentages of breeds treated within and between years were responsible for the shorter gestation periods, especially in the dairy breeds. Dairy cows having a large percentage treated were more affected. Within dairy cattle, Brown Swiss, with fewer calving animals than Holstein, would appear to be the most affected by the treatment.

When the three degrees of freedom were broken down to single degrees of freedom for orthogonal comparison (Tables 17 and 18), as was expected from results prior to this analysis, the gestation length of beef cattle exceeded that of dairy animals by 3.5 days.

Differences due to the sire of the calf had a significant effect on gestation length. Cows mated to beef sires had longer gestation periods than those mated to dairy bulls regardless of the breed of dam (Tables 15 and 16). This confirms the genetic effect of gestation length and the importance of the genotype of the calf. Calves sired by Holstein bulls were carried for the shortest length of time.

Females which received Azium or Flucort to hasten the onset of parturition had shorter gestation lengths, in a range from 0.5 to 1.9 days, which shows that the treatment was effective in terminating pregnancy. The role of corticoids in parturition have been treated by Adams (1969), Adams and Wagner (1970) and Wright _et al_. (1970). Adams and Wagner (1970) found that the level of prepartum plasma corticoid in normal cows rose 4 days prior to parturition when compared with the levels on days 5 to 7 prepartum and days 3 to 7 postpartum. On the other hand, plasma corticoid levels dropped drastically in cows treated with 20 mg of dexamethasone. Adams and Wagner suggested that the rise in plasma corticoids and the accompanying decline in corpus luteum function may be related to the onset of parturition. The regression of corpus luteum and a decline in plasma progesterone levels after treatment with corticoids, were pointed out by Wright et al. 1970. The largest effect of the treatment was shown for cows which calved three consecutive times (group 7).

Sex effect was not clear in the analyses. In 1969, sex reached significance. However, the differences between sexes was only 1 day. Small residual sums of squares contributed to this significance.

The effect of the weight of cow on the length of gestation, measured as a regression of precalving and postcalving average daily gain on gestation length, was found not to be important. Similar conclusions were reported in cattle by Knapp et al. (1940) and in sheep by Terril and Hazel (1947). However, the consistent negative tendency (b = -0.17 to -0.25) suggests a negative correlation between average daily gain after parturition and length of gestation period. Cows with heavier calves (long gestation period) lose weight within 60 days after parturition. Stress at parturition and nursing effect might explain this negative correlation between average daily gain after parturition and length of gestation period.

Among the various influences on gestation length, the characteristics of the calf are the most important. Birth weight, dam and sire of the calf, accounted for the most of the variation in gestation length. Farm and treatment to conclude gestation were other important sources of variation. Azium and Flucort were effective in inducing labor and parturition in cattle.

No differences were found on gestation length between group of cows calved once, twice and three times. Nevertheless, a non-significant parity effect of the dam was noticed.

Analysis II

Calving interval

Calving interval and the number of services per conception have been reported as common measures of fertility (Brown *et al.*, 1954; Johansson, 1961; Maijala, 1964; Everett *et al.*, 1966). Most of the work has been done in dairy cattle. Literature is in agreement that environmental factors are more important than genetic factors (Brown *et al.*, 1954; Rennie, 1952; Maijala, 1964 and Foote, 1970). In addition, additive genetic variance seems to be near zero (Brown *et al.*, 1954; Legates, 1954; Ødegård, 1965 and Foote, 1970). However, there is a paucity of information in which environmental factors are the more important sources of variation on calving interval.

Model 1, described in the section on the method of analyses was used to study calving interval. Models 2, 3 and 4 were used for postpartum interval, conception length and gestation length in the least-squares analyses. The analyses were carried out comparing animals with one calving interval against animals with two. The purpose was to compare reproductive performance of two beef and two dairy breeds used in single cross beef production.

Not all the animals who calved twice were included in the analyses. Group 6 (cows calving in 1968 and 1970) were excluded from the analyses on the grounds of the definition given in source of data. The groups of animals studied represent a selected set of the initial population. They are also the animals who had a successful calving in 1968 and 1969. Thus, comparison between groups of cows calving in 1968-9 defined phase I of Analysis II. Group 4 failed to calve in 1970.

The interclass correlation between the four reproductive traits for Analysis II, phase I, is presented in Table 19. The results of the least-squares analysis is shown in Table 21. Constant estimates for main effect and regressions are given in Table 23 and the analysis of orthogonal comparisons in Table 25. The overall mean for calving interval for Analysis II, phase I, was 375.0 days with a standard deviation of 21.5 days which results in a coefficient of variation of 5.8%. The overall mean and standard deviation for conception length, postpartum interval and gestation length for this analysis were 10.8 ± 15.4, 85.3 ± 23.1 and 278.9 ± 5.9 days respectively. Similarly, the coefficients of variation for these traits were 142.9%, 27.1% and 2.1%. The relative importance of postpartum interval, conception length and gestation length in contributing to the variability of calving interval was examined. The standarized partial regression coefficient for calving interval on postpartum interval was 1.06 and similarly for conception length was 0.70 and for gestation length was 0.24. The relative weights of these coefficients in percentage were 52.9, 35.2 and 11.2 for postpartum interval, conception length and gestation length respectively. Thus, postpartum interval explains most of the variation in calving interval. In general, the animals which had the longer postpartum interval had the longest calving interval. These results are in disagreement with the results published from dairy cattle by Chapman and Casida (1935), VanDemark and Salisbury (1950) and Everett et al. (1966). Dairy cattle studies reported that postpartum interval and gestation length behaved as a constant and cows with long postpartum intervals had difficulty becoming pregnant. Data from dairy cattle suggest that conception lengths are responsible for most of the variation in calving interval. In this study, the animals were subjected to a fixed breeding date and allowed a fixed length to rebreed. Fewer restrictions on breeding exist in dairy cattle where the animals may be mated at all seasons of the year.

In Analysis II, phase II, comparisons were made between groups of animals with one calving interval (group 5) and two calving intervals (group 7) in 1970. Cows from group 5 failed to calve in 1968.

The interclass correlations between the four reproductive traits are presented in Table 20. Least-squares analysis for this phase is given in Table 22. Constant estimates for main effect and regressions are presented in Table 24 and the analysis of orthogonal comparisons in Table 26. The overall mean for calving interval was 358.1 with a standard deviation of 28.9 days. Conception length, postpartum interval and gestation length had overall means and standard deviations of 7.9 ± 15.2, 73.5 ± 26.3 and 276.6 ± 6.3 days respectively. The coefficients of variation were 2.3%, 8.1%, 35.7% and 192.0% for gestation length, calving interval, postpartum interval and conception length respectively. The standarized partial regression coefficient for calving interval on postpartum interval was 0.90 and similarly for conception length was 0.61 and for gestation length was 0.25. The relative weights of the standarized partial regression coefficient for postpartum interval, conception length and gestation length on calving interval were: 51.1%, 34.9% and 14.0% respectively. The results in phase II verify the findings in phase I. As a result of these analyses (phase I and II), postpartum interval contributes the most variation to calving interval. The only reproductive trait acting nearly as a constant was gestation length. Short postpartum intervals lead to a shorter calving interval in these data.

The shortest postpartum intervals were among Hereford cows in phase I of Analysis II and among Angus cows in phase II of the same analysis. Compared with Brown Swiss, which had the longest postpartum interval, Herefords were 20.8 days shorter and Angus 5.9 days shorter. Herefords had the shortest postpartum and calving interval in phase I, whereas Holsteins had a shorter calving interval in phase II due to a shorter conception length and period of gestation simultaneously.

In group 7, the first calving interval was longer by 12.0 days than the second calving interval. Longer first calving intervals have been reported by Rennie (1952), Brown *et al*. (1954) and Ødegård (1965). Longer first calving intervals are partly explained in these data by a longer first postpartum interval.

Since there were differences between breeds in postpartum

Table 19. Simple correlations among four reproductive traits involving cows calving in 1968 and 1969 (Groups 4 and 7) - Analysis II

Row variable No.[a]	Column variable number[a]			
	1	2	3	4
1	1.000			
2	0.790	1.000		
3	0.324	-0.288	1.000	
4	-0.270	-0.275	-0.309	1.000

[a]The variables are: 1 = calving interval, 2 = postpartum interval, 3 = conception length, 4 = gestation length.

Table 20. Simple correlations among four reproductive traits involving cows calving in 1969 and 1970 (Groups 5 and 7) - Analysis II

Row variable No.[a]	Column variable number[a]			
	1	2	3	4
1	1.000			
2	0.782	1.000		
3	0.366	-0.243	1.000	
4	0.287	0.129	-0.122	1.000

[a]The variables are: 1 = calving interval, 2 = postpartum interval, 3 = conception length, 4 = gestation length.

Table 21. Mean squares for four reproductive traits of cows calving in 1968 and 1969 (Groups 4 and 7) - Analysis II

Source[1]	d.f.	Reproductive Calving interval
Group	1	488.12
Breed of cow	3	218.50
Breed of sire (1)[a]	3	102.74
Breed of sire (2)	---	---
Farm	1	1,517.55**
Assistance (1)	1	876.33*
Sex (1)	---	---
Sex (2)	---	---
Calving period	6	6,877.75**
$Treatment_{14}$[d]	1	6,330.84**
$Treatment_{17}$	1	23,223.01**
Breed of cow x breed of sire (1)[p]	---	---
Breed of cow x breed of sire (2)	---	---
Breed of cow x farm	3	142.17
Breed of sire (1) x farm	3	72.36
Breed of sire (2) x farm	---	---

[p]Interaction effect

*P < 0.05

**P < 0.01

traits					
d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
1	3,431.20**	1	16.62	1	3.63
3	2,268.66**	3	569.53*	3	197.48**
3	797.29*	3	772.42*	---	---
---	---	---	---	3	30.63
1	4,700.44*	1	32.22	1	54.28
1	40.31	1	993.68**	1	5.07
1	1,844.23*	---	---	---	---
---	---	---	---	1	48.17
6	6,694.57*	6	52.28	---	---
---	---	---	---	1	132.78*
---	---	---	---	1	309.87**
9	295.74	---	---	---	---
---	---	---	---	9	41.54
3	655.31	3	431.11	3	64.96
3	590.69	3	284.65	---	---
---	---	---	---	3	27.46

Table 21. (Continued)

Source[1]	d.f.	Reproductive: Calving interval
b_1^c	1	783.32*
b_2^e	1	1,153.51**
b_3^c	1	109.77
b_4	1	444.36
Remainder	228	149.06

traits

d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
1	249.00	1	153.53	---	---
---	---	---	---	1	1,389.71**
1	3.54	1	0.52	1	0.37
1	1,534.96*	1	11.43	1	4.31
225	295.69	226	217.29	215	24.57

Table 22. Mean squares for four reproductive traits of cow calving in 1969 and 1970 (Groups 5 and 7) - Analysis II

Source[1]	d.f.	Reproductive: Calving interval
Group	1	101.27
Breed of cow	3	159.48
Breed of sire (2)[a]	3	289.22
Breed of sire (3)	---	---
Farm	1	10,574.15**
Assistance (2)	1	900.28
Sex (2)	---	---
Sex (3)	---	---
Calving period	7	5,534.84**
$Treatment_{15}$[d]	1	334.53
$Treatment_{17}$	1	3,149.69**
$Treatment_{25}$	1	1,372.11
$Treatment_{27}$	1	353.48
Breed of cow x breed of sire (2)[p]	---	---
Breed of cow x breed of sire (3)	---	---
Breed of cow x farm	3	1,476.89*
Breed of sire (2) x farm	3	398.41
Breed of sire (3) x farm	---	---

*P < 0.05

**P < 0.01

traits					
d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
1	0.04	1	0.24	1	148.53**
3	228.34	3	110.73	1	98.46*
3	32.00	3	233.39	---	---
---	---	---	---	3	1.89
1	12.256.73**	1	39.10	1	270.67**
1	33.86	1	942.45**	1	3.33
1	0.00	---	---	---	---
---	---	---	---	1	41.97
7	5,790.92**	7	236.21	---	---
1	99.20	1	17.88	---	---
1	1,760.82*	1	80.45	---	---
---	---	---	---	1	17.12
---	---	---	---	1	142.24**
9	215.42	---	---	---	---
---	---	---	---	9	10.14
3	1,082.80*	3	412.60	3	13.48
3	23.48	3	218.44	---	---
---	---	---	---	3	17.76

Table 22. (Continued)

Source[1]	d.f.	Reproductive Calving interval
b_1^c	1	2,542.11**
b_2^e	1	27.19
b_3^c	1	2,503.92*
b_4	1	1,127.07
Remainder	278	382.72

traits

d.f.	Postpartum interval	d.f.	Conception length	d.f.	Gestation length
1	937.77	1	341.34	---	---
---	---	---	---	1	585.27**
1	1,867.21*	1	15.74	1	28.67
1	527.72	1	85.65	1	4.93
270	309.87	265	230.21	257	19.30

Table 23. Constant estimates of main effects and regressions and their standard errors for four reproductive traits of cow calving in 1968 and 1969 (Groups 4 and 7) - Analysis II

Constant[1]	Calving interval	Postpartum interval	Conception length	Gestation length
μ	376.82 ± 1.97	93.21 ± 2.63	10.29 ± 2.25	279.76 ± 0.57
Group 4[g]	1.68 ± 2.38	4.25 ± 3.05	-0.29 ± 2.64	-0.15 ± 0.76
Group 7[h]	-1.68 ± 1.96	-4.25 ± 2.77	0.29 ± 2.32	0.15 ± 0.62
Breed of cow 1[i]	-3.26 ± 2.90	-4.94 ± 3.78	2.23 ± 3.22	1.69 ± 0.90
Breed of cow 2	-3.14 ± 2.57	-11.18 ± 3.52	5.44 ± 2.99	2.80 ± 0.76
Breed of cow 3	1.13 ± 2.35	6.50 ± 3.27	-1.41 ± 2.79	-2.76 ± 0.83
Breed of cow 4	5.27 ± 4.05	9.62 ± 5.14	-6.26 ± 4.10	-1.73 ± 1.68
Breed of sire (1)[a] 1[i]	1.07 ± 3.11	-0.31 ± 4.31	5.29 ± 3.63	0.34 ± 1.10
Breed of sire (1) 2	-2.22 ± 2.44	-0.21 ± 3.25	-3.04 ± 2.77	1.08 ± 0.83
Breed of sire (1) 3	1.08 ± 2.35	6.01 ± 3.54	-4.56 ± 2.77	-1.03 ± 0.93
Breed of sire (1) 4	0.08 ± 2.55	-5.48 ± 3.50	2.31 ± 2.99	-0.39 ± 0.89
Farm 1	-4.54 ± 1.85	-7.15 ± 2.54	0.57 ± 2.17	-0.88 ± 0.45
Farm 2	4.54 ± 2.90	7.15 ± 3.72	-0.57 ± 3.14	0.88 ± 1.07
$Assistance_{10}$[j]	2.23 ± 2.10	-0.49 ± 2.78	2.38 ± 2.38	0.17 ± 0.64

Table 23. (Continued)

Constant[1]	Calving interval	Postpartum interval	Conception length	Gestation length
Assistance$_{11}$	-2.23 ± 2.25	0.49 ± 3.10	-2.38 ± 2.63	-0.17 ± 0.73
Sex (1) male	--- ---	2.93 ± 2.81	--- ---	--- ---
Sex (1) female	--- ---	-2.93 ± 2.95	--- ---	--- ---
Sex (2) male	--- ---	--- ---	--- ---	-0.50 ± 0.68
Sex (2) female	--- ---	--- ---	--- ---	0.50 ± 0.67
Calving period 2[k]	20.90 ± 7.92	12.47 ± 11.32	7.07 ± 9.51	--- ---
Calving period 3	25.20 ± 4.44	25.54 ± 6.14	-0.80 ± 5.49	--- ---
Calving period 4	20.43 ± 2.39	20.48 ± 3.26	-0.41 ± 2.77	--- ---
Calving period 5	2.27 ± 1.82	0.06 ± 2.35	-2.22 ± 1.93	--- ---
Calving period 6	-11.35 ± 2.11	-14.39 ± 2.92	-0.33 ± 2.47	--- ---
Calving period 7	-20.26 ± 2.19	-19.21 ± 3.02	-0.76 ± 2.51	--- ---
Calving period 8	-37.19 ± 5.84	-24.96 ± 8.23	-2.54 ± 6.91	--- ---
Treatment$_{104}$[o]	-10.24 ± 3.26	--- ---	--- ---	1.47 ± 1.14
Treatment$_{114}$	10.24 ± 2.38	--- ---	--- ---	-1.47 ± 0.82
Treatment$_{107}$	-12.74 ± 2.31	--- ---	--- ---	1.52 ± 0.80

Table 23. (Continued)

Constant[1]	Calving interval	Postpartum interval	Conception length	Gestation length
Treatment_{117}	12.74 ± 2.10	--- ---	--- ---	-1.52 ± 0.71
b_1^c	-0.24 ± 0.10	-0.15 ± 0.15	0.10 ± 0.12	--- ---
b_2^e	-0.23 ± 0.08	--- ---	--- ---	0.27 ± 0.04
b_3^c	0.63 ± 0.73	-0.11 ± 1.05	-0.04 ± 0.88	0.03 ± 0.25
b_4	-2.55 ± 1.48	-4.85 ± 2.13	-0.41 ± 1.79	-0.25 ± 0.60

Table 24. Constant estimates of main effects and regressions and their standard errors for four reproductive traits of cow calving in 1969 and 1970 (Groups 5 and 7) - Analysis II

Constant[1]	Calving interval	Postpartum interval	Conception length	Gestation length
μ	367.51 ± 2.96	78.36 ± 2.78	10.37 ± 2.41	277.86 ± 0.49
Group 5[m]	0.96 ± 3.81	-0.02 ± 3.57	-0.05 ± 3.12	-0.84 ± 0.60
Group 7[h]	0.96 ± 3.17	0.02 ± 2.92	0.05 ± 2.51	0.84 ± 0.55
Breed of cow 1[i]	-1.33 ± 3.78	-2.39 ± 3.46	1.66 ± 3.08	0.63 ± 0.66
Breed of cow 2	0.06 ± 3.88	-2.15 ± 3.57	1.77 ± 3.17	1.87 ± 0.73
Breed of cow 3	-1.45 ± 3.96	0.98 ± 3.49	-1.15 ± 3.06	-2.36 ± 0.90
Breed of cow 4	2.72 ± 4.23	3.55 ± 3.97	-2.27 ± 3.46	-0.14 ± 0.98
Breed of sire (2)[a] 1[i]	2.63 ± 3.84	-0.43 ± 3.65	2.18 ± 3.17	-0.15 ± 0.77
Breed of sire (2) 2	-2.24 ± 3.53	0.86 ± 3.27	0.57 ± 2.84	-0.24 ± 0.89
Breed of sire (2) 3	0.71 ± 3.73	0.29 ± 3.56	0.12 ± 3.08	0.25 ± 0.78
Breed of sire (2) 4	-1.09 ± 3.48	-0.73 ± 3.28	-2.87 ± 2.79	0.13 ± 0.70
Farm 1	-20.09 ± 4.70	-8.94 ± 2.87	-0.52 ± 2.42	-3.21 ± 0.91
Farm 2	20.09 ± 4.97	8.94 ± 3.37	0.52 ± 2.99	3.21 ± 1.06
Assistance$_{20}$[j]	-2.96 ± 2.93	-0.57 ± 2.68	-3.05 ± 2.30	0.18 ± 0.38

Table 24. (Continued)

Constant[1]	Calving interval	Postpartum interval	Conception length	Gestation length
Assistance$_{21}$	2.96 ± 4.05	0.57 ± 3.78	3.05 ± 3.30	-0.18 ± 0.83
Sex (2) male	--- ---	0.00 ± 2.99	--- ± ---	--- ---
Sex (2) female	--- ---	-0.00 ± 3.01	--- ---	--- ---
Sex (3) male	--- ---	--- ---	--- ---	-0.42 ± 0.56
Sex (3) female	--- ---	--- ---	--- ---	0.42 ± 0.57
Calving period 1[n]	34.66 ± 7.39	32.47 ± 6.55	5.51 ± 5.92	--- ---
Calving period 2[k]	28.46 ± 4.65	31.96 ± 4.19	-2.67 ± 3.70	--- ---
Calving period 3	16.41 ± 4.25	13.91 ± 3.89	1.72 ± 3.42	--- ---
Calving period 4	7.61 ± 4.20	10.25 ± 3.85	-4.08 ± 3.40	--- ---
Calving period 5	2.37 ± 4.70	-2.95 ± 4.17	4.27 ± 3.69	--- ---
Calving period 6	-17.49 ± 3.22	-16.22 ± 2.97	-0.19 ± 2.65	--- ---
Calving period 7	-21.17 ± 3.60	-18.08 ± 3.23	-1.00 ± 2.81	--- ---
Calving period 8	-50.85 ± 14.72	-51.34 ± 13.52	-3.56 ± 11.42	--- ---
Treatment$_{105}$[o]	-3.54 ± 3.41	-1.92 ± 3.10	-0.84 ± 2.69	--- ---
Treatment$_{115}$	3.54 ± 6.73	1.92 ± 6.24	0.84 ± 5.51	--- ---

Table 24. (Continued)

Constant[1]	Calving interval	Postpartum interval	Conception length	Gestation length
$Treatment_{107}$	-6.46 ± 3.41	-4.86 ± 3.14	-1.04 ± 2.69	--- ---
$Treatment_{117}$	6.46 ± 4.31	4.86 ± 3.94	1.04 ± 3.39	--- ---
$Treatment_{205}$	-7.78 ± 5.72	--- ---	--- ---	0.86 ± 1.13
$Treatment_{215}$	7.78 ± 5.49	--- ---	--- ---	-0.86 ± 1.05
$Treatment_{207}$	-3.73 ± 5.15	--- ---	--- ---	2.36 ± 1.05
$Treatment_{217}$	3.73 ± 4.86	--- ---	--- ---	-2.36 ± 1.01
$b_1{}^c$	0.35 ± 0.13	0.21 ± 0.12	0.12 ± 0.10	--- ---
$b_2{}^e$	-0.03 ± 0.11	--- ---	--- ---	0.14 ± 0.03
$b_3{}^c$	3.43 ± 1.34	2.93 ± 1.91	0.28 ± 1.09	0.39 ± 0.32
b_4	2.56 ± 1.49	1.82 ± 1.39	0.71 ± 1.17	-0.17 ± 0.34

Table 25. Mean squares for orthogonal comparisons among breed of cow and breed of sire on four reproductive traits for cows calving in 1968 and 1969 (Groups 4 and 7) - Analysis II

Comparisons	Reproductive traits							
	Calving interval		Postpartum interval		Conception length		Gestation length	
	Cow[a]	Sire[b]	Cow	Sire	Cow	Sire	Cow	Sire
Beef vs. dairy	646.07*	44.06	4,915.14**	8.81	1,252.50*	179.70	332.93**	62.27
Angus vs. Hereford	0.34	193.17	973.02	0.16	268.10	1,257.42*	28.42	9.05
Holstein vs. Brown Swiss	143.55	22.12	98.77	2,389.61**	272.79	1,019.51*	8.29	7.00

[a]Cow = breed of cow.

[b]Sire = breed of sire of the corresponding mating for these traits.

*P < 0.05.

**P < 0.01.

Table 26. Mean squares for orthogonal comparisons among breed of cow and breed of sire on four reproductive traits for cows calving in 1969 and 1970 (Groups 5 and 7) - Analysis II

Comparisons	Reproductive traits							
	Calving interval		Postpartum interval		Conception length		Gestation length	
	Cow[a]	Sire[b]	Cow	Sire	Cow	Sire	Cow	Sire
Beef vs. dairy	43.55	8.81	602.31	10.04	322.93	411.61	173.68**	5.51
Angus vs. Hereford	71.61	755.06	2.07	49.01	0.41	77.33	50.15	0.12
Holstein vs. Brown Swiss	393.56	108.34	150.02	30.44	11.28	257.62	60.01	0.33

[a]Cow = breed of cow.

[b]Sire = breed of sire of the corresponding mating for these traits.

**P < 0.01

interval, orthogonal comparisons were performed and the results are presented in Tables 25 and 26. The postpartum interval averaged 80.6 for beef cows compared with an average of 90.8 days for dairy animals. However, when comparisons are made on means of calving intervals for beef and dairy types, the differences are less than 2 days. The reduction in the difference in calving interval compared with the difference observed on postpartum interval is due to shorter conception length and gestation length for dairy cows. These were dairy cows that did calve. Thus, it appears that dairy cows under beef management had a longer postpartum interval. Age of the cow and suckling effects may be considered in trying to explain these differences between dairy and beef cows (Lauderdale _et al_., 1968 and Saiduddin _et al_., 1968). Another important consideration is the treatment effect. More dairy cows were injected with Azium or Flucort than beef cows. The longer postpartum interval of dairy cows compared with beef cattle was reported by Casida and Wisnicky (1950) and Hafez (1968). In spite of that, Holstein cows performed as well as beef cattle in reproduction performance measured as total number of calves. Thus, calving interval alone as a measure of reproduction at least in beef production, is doubtful. Under a beef management system (fixed breeding season, short breeding season, calving season, etc.) it is not likely that important differences will exist between calving intervals of cows.

Cows which calved twice (Group 4) had a longer postpartum and calving interval than cows calved three times (Group 7) in Analysis II, phase I, (Table 23). The results are not similar when comparisons were made between cows calved twice (Group 5) and cows calved three times (Group 7) in Analysis II, phase II, (Table 24). Here, animals classed in group 5 had shorter postpartum intervals and calving intervals than cows of group 7. The results might suggest a parity effect of the dam since group 5 cows calved first at 3 years of age. This effect appears to reduce the difference between groups of cows. Group 5 may not have failed in 1971, so are like group 7, but started later. Group 4 failed to calve in 1970.

From the results of Analysis II (Tables 21 and 22), no difference was observed in conception length between cows which had 2 or more calvings. Consequently, no influence on calving interval due to conception length is inferred for cows with 2 or more parturitions. Nevertheless, the effect of breed of cow was manifest at the beginning of their reproductive life. Breed of cow showed a significant effect on conception length. The least-squares means of 15.7, 12.5, 8.9 and 4.0 days were obtained for Hereford, Angus, Holstein and Brown Swiss breeds. However, these differences were not shown in calving interval due to the masking effect of postpartum interval. Since Brown Swiss showed the shortest conception length and also the lowest reproductive efficiency (total number of calves), that breed would appear to have had problems both in starting the estrus cycle (long postpartum interval) and in becoming pregnant. Thus, there were fewer Brown Swiss cows, those who conceived in a short period of time, in Analysis II. There is no basis to suppose that discrimination against Brown Swiss was practiced. Some problems on reproduction is inferred from the results.

Sires used in the mating had a significant effect. Bulls from the Hereford and Holstein breeds showed the lowest conception length when they were mated to cows in group 4 and 7 (phase I). This might suggest that fertility varied according to the breed of sire. No explanation can be offered for these facts other than that there was a particular effect of the semen from the sires when breeding cows in those specific groups.

The analysis of single degree of freedom comparison among type of cattle and breeds is shown in Table 25 and Table 26. Beef cattle had longer conception lengths in both phase I and II than did dairy cows. Dairy types had shorter lengths (7.7 days) than beef types. Within type of breed, the largest difference was found between Angus and Hereford animals. Angus cows were 5.9 days longer in conception lengths than Hereford cows. There was no clear difference between the dairy cattle breeds in conception length either in phase I or phase II in Analysis II.

Breed of cows differ in gestation length in both phase I and phase II of Analysis II. The average least-squares estimates were 281.2, 280.0, 277.5 and 276.3 days for Hereford, Angus, Brown Swiss and Holstein cattle respectively. These figures are perhaps a little lower than those reported in the literature. Part of the difference is due to treatment effect (Azium or Flucort) regardless of breed of cow and part is that more dairy type cattle received Azium than beef type. Then dairy type cattle would be expected to have lower gestation length in this study than those reported by Jafar et al. (1950), DeFries et al. (1958), Konce (1968) and BreDahl (1970). However, the contribution of gestation to the variability of calving interval is negligible. As expected from previous results, in the orthogonal comparisons the gestation length for beef cattle exceeded the gestation length for dairy animals; in this analysis, the difference was 4.5 days.

The importance of each factor on calving interval, postpartum interval, conception length, and gestation length was examined under the models described in the method of analysis section.

Farm, calving period, treatment within groups of cow, and birth weight of the second calf were the most significant sources of variation for phase I (Table 21). Assistance at calving and birth weight of the first calf were significant at the 5% probability level. In phase II (Table 22), farm, calving period and treatment were highly significant sources of variation, whereas the breed of cow x farm interaction, birth weight of the first calf in this period and precalving average daily weight gain were significant ($P < 0.05$).

Assistance given at parturition was a highly significant source of variation in conception length in both phases of Analysis II. The control of the variation explained for farm, calving period, nested effect of treatment within groups and birth weight of the calf can be of practical application in improving reproduction efficiency in cattle. But breed of cow x farm interactions are not as simple to include in an improved reproduction program.

The least-squares estimators for mean calving interval were 372.3 and 381.4 days in 1968-9 for farm 1 and 2 respectively. For 1969-70, the estimates were 347.4 and 387.6 for farm 1 and 2 respectively. The difference between farms was also found in postpartum interval for the same period and was the most important source of variation.

The effect of postpartum interval can also be detected in the analysis of calving period for the data under study. In the years 1968-9 and 1969-70, cows which calved early in the season had, on the average, 58 and 79 days longer calving interval than cows which calved later. This was due to the fixed date for the start of the breeding season. There was great variation between least-squares estimates for 2 consecutive calving periods. The shortest difference in 1968-9 analysis was found between calving period 2 and 3 (4.3 days), while in 1969-70, this was between calving period 6 and 7 (3.7 days) in Tables 24 and 25. The largest differences in 1968-9 analysis was between calving periods 4 and 5 (18.7 days); correspondingly, calving period 7 and 8 had the largest difference (29.7 days) in 1969-70 analysis. In 1969-70, cows that calved later required fewer services than in 1968-9 and consequently, a greater difference was shown between early and later calving cows due to shorter conception lengths of the latter. Also, there were more dairy cows which calved later and thus received Azium or Flucort than beef cows. The effect of treatment will be discussed further.

The nested effect of treatment within group (Azium or Flucort) was another important cause of variation. Cows differed as much as 25 days in calving interval according to whether they received treatment. Those which did not receive Azium or Flucort showed smaller calving intervals than animals which did, even after adjustment for calving period. The same treatment effect was found for postpartum interval and conception length. Animals which received shots of Azium or Flucort had a longer postpartum interval and conceived over a longer period of time than animals who did not. This implies a delayed effect in returning to estrus after parturition and this is reflected in conception length. The delay on returning to first recorded heat is expected since some complication after parturition follows the treatment, retained placenta (Adams and Wagner, 1970). Complications after parturition, due to the treatment might affect the interval from first service to service of conception.

The effect of birth weight on calving interval of the first and second calf was not consistent in Analysis II. In 1968-9, the sum of squares due to the regression of birth weight of the first calf was a significant source of variation ($P < 0.05$) while the birth weight of the second calf was highly significant ($P < 0.01$). In 1969-70, only the birth weight of the first calf for this calving interval was significant ($P < 0.05$). Age and parity of the dam could explain the divergence, but more investigation is needed to clarify this effect.

Assistance was a highly significant source of variation in conception length for cows with two or more parturitions. Among the heifers calving at 2 years of age, those that received assistance had a shorter conception length than those that did not. But among the 3-year-old cows, those that did not receive assistance had a shorter conception length. The effect of assistance was only manifest on calving interval in phase I of Analysis II. Cows who had assistance had a 4.4

day shorter calving interval.

The regression of precalving average daily weight gain on calving interval was significant ($P < 0.05$) and positive in phase II, but not significant in phase I. The practice of maintaining pregnant cows in good condition, but not to permit too much gain in weight, is supported by this finding.

Environmental factors; such as farm, assistance given to the cow at parturition, calving period, treatment to conclude gestation, and birth weight of the calf; were found to be important in explaining part of the total variation in calving interval among four breeds of cows that were grouped according to the number of calves. The effect of parity of the cow did not change the importance of these sources of variation. Breeds of cow differed initially on reproductive performance measured as postpartum interval, conception length, gestation length and the sums of these three, calving interval. Later, these differences became partially confounded with calving period and treatment.

The first calving interval was, on the average, somewhat longer than the second for farm 1. A similar result was reported by Brown et al. (1954) working with Angus cattle and Ødegård (1965) analyzing data from Norwegian Red cattle. In spite of the divergence of the results, at least four sources of variation (farm, calving period, treatment and birth weight of the calf), have shown an effect on calving interval and two of its components (postpartum interval and gestation length). Conception length was influenced by a different set of factors than the other periods. Assistance given to the cow at parturition especially when assistance was given at the first calving, seems to be the only important environmental factor that explained part of the variation in conception length. Whether or not this is due to damages in the reproductive tract which impaired future performance or is the result of management of these brood cows, remains as an open question. Sagebiel _et_ _al_. (1969) and BreDahl (1970) discussed and studied in detail the effect of distocia in cows. Nevertheless, some improvement might be expected by controlling any or all of the factors mentioned.

Length of calving interval is not an absolute measure of reproduction. Short calving intervals are not associated with number of calves. Calving interval does not reveal the absolutely sterile heifer or the breeding abnormalities of the cow in a population culled before second calving. Postpartum interval and conception length studied in a sequence of time can be used as indicators to detect reproductive problems in brood cows.

Results from the analysis of proportions and Analyses I and II

Analysis of variance of the proportions of cows calving by breed, farm and year and their interactions showed that breed, farm and the interaction of breed with year were highly significant sources of variation. Results indicate that large differences exist among farms (20.5%) and among breeds (14.7%) for calf crop percentage.

The results from Analysis I and Analysis II indicate that breed of cow, farm, assistance, calving period and treatment (Azium or Flucort) are important sources of variation which help to explain the variability of calving interval, postpartum interval and conception length. In addition, birth weight of the calf was the major factor to determine the length of gestation. These important factors which influence reproductive performance, rather than the reproductive traits themselves, are useful in trying to explain the differences in the calf crop percentage among breeds. In so doing, the effects of these factors can be observed across the various traits.

Breed of cow had an effect at the beginning of the reproductive life of the cow. Both in 1968 and in 1968-9, breed of cow appeared as an important source of variation ($P < 0.05$ to $P < 0.01$) in postpartum interval, conception length and gestation length. Holstein, the breed with best reproductive performance at the beginning (72.0%), declined through the years to 54.6%, while Angus increased 20.0%. Even though breeds performed differently in 1969 and 1969-70, no breed differences were found significant for postpartum interval and conception length in the analyses. The lack of breed differences can be explained by the management system practiced in which the effects of farm, calving periods and treatment were of major importance and are partially confounded with breeds.

The farm effect appears consistently as an important factor in the variability of the four reproductive traits. Some components of the farm effect, such as nutrition level, care of breeding cows, techniques and accuracy of heat detection may explain the 20.5% difference in calf crop between farm 1 and 2. Some contribution to that difference might also come from the assistance and treatment effect, which are partially confounded with the farm effect. Assistance given at parturition was an important source of variation in conception length. Assistance at parturition given to the heifer shortened the conception length in 4.8 days. But assistance to the older cows lengthened conception length by 6.1 days. More animals received assistance at farm 1 than at farm 2.

Calving period was an important source of variation in length of postpartum interval and calving interval. Some confounding of calving period effect with treatment and breed of cow was generated by certain constraints in the management system, namely a terminal date for the calving season and a fixed period for the breeding season. Such constraints require that a cow become pregnant within an interval of about 100 days, including postpartum interval and conception length, if one calf per year is desired. Cows calving early had a postpartum interval of around 115 days while cows calving late had around a 48 day interval.

Treatment to conclude gestation was an important factor effecting the variability of postpartum interval and conception length. The number of cows treated was not equal between farms. More cows on farm 1 received treatment than cows on farm 2. Treatment was also associated with calving period and breed of cow. Animals calving later were injected with Azium or Flucort and among them were more dairy cows than beef cattle. The effect of the corticoids given the cows lengthened postpartum interval and conception length. Cows which received treatment, on the average, had a 6.8 day longer postpartum interval and a 1.9 day longer conception length than those not treated. The treatment effect with a fixed period for breeding and calving season might affect the reproductive performance of the breeds. These factors can help to explain the highly significant effect of breed x year interaction found in the analysis of proportion.

Besides the importance of the calf weight at birth in determining the length of gestation, the treatment was also an important factor.

Different breeds of cows performed differently, but the management system can change the response of the breeds when measured in calf crop production. Factors such as breed of cow, farm, assistance, calving period and treatment were among the sources of variation which may influence the reproductive performance of the cow by affecting postpartum interval, conception length and calving interval. However, compounds of dexamethasone or flucortin can be used to shorten the gestation length as desired but postpartum interval and conception length will be lengthened.

SUMMARY AND CONCLUSIONS

Calving interval, postpartum interval, conception length and gestation length were studied in 1,303 parturitions involving Angus, Hereford, Holstein and Brown Swiss cows, over a three-year period in two Iowa State University experimental farms. Data were collected from cows which calved in any or all of the years 1968, 1969 and 1970. In 1968, a total of 800 cows were exposed and 470 calves were born. In 1969, from 794 cows exposed, 474 calved. In 1970, 359 calves were obtained from 627 cows bred.

The fertility of two beef and dairy breeds, measured as the proportion of cows calving in each year, was analyzed using a χ^2 procedure. Breeds, farms and the interaction of breed with years, were highly significant sources of variation. Over the three years, 64.7%, 60.3%, 59.4% and 50.0% of the cows exposed calved in the Holstein, Angus, Hereford and Brown Swiss breeds respectively. The difference between the most and least prolific breeds (Holstein and Brown Swiss) was 14.7% over that period of time. On farm one, 780 calves were recorded from 1,136 exposed cows (68.7%) and on farm two, 523 calves were recorded from 1,085 exposed (48.2%). The breed x year interaction was highly significant; this suggests that either the breeds reacted differentially each year or the breeds responded differentially during the sequence of years. A decline in fertility was observed in the dairy cows during the years studied, while the reverse tendency was found among the beef cattle. The decreasing reproductive performance in dairy cows might be explained as a response of dairy cattle to a beef system that has a breeding and calving season as well as to a suckling effect. Treatment with corticoids (Azium and Flucort) was given to the cows to conclude gestation. Treatment was associated with farm, calving period, breed of cow and year. No treatment was given in 1968. But more cows were treated in 1970 than in 1969 and among them, more dairy cows. Cows which received treatment, on the average, had a 6.8 day longer postpartum interval and a 1.9 day longer conception length than did cows not treated. The effect of the treatment over the years might explain the highly significant effect of the breed x year interaction found in the analysis of proportion. There is evidence that genetic (breeds), environmental (farms and years) and genetic x environmental interaction (breeds x years) are important sources of variation for reproductive performance in beef and dairy cattle when managed under beef conditions. In evaluating the reproductive performance of several breeds, the year in which records were made should be taken into consideration. To assess the value of dairy breeds in beef production, they should be studied over a series of years to consider a possible loss of reproductive performance.

Two other analyses (I and II) were carried out to study the effect of type, breeds and various environmental factors on reproductive traits of the four breeds when managed under beef conditions. Constant estimates for each factor in the models were fitted simultaneously. In doing so, the data were adjusted for the effect of calving period, farm and the other important factors. Analysis I deals with cows calved any number of times in 1968 and 1969, while Analysis II considered only those which calved more than once over the three-year period. Analysis I was broken down into 2 phases, phase I including those cows which calved in 1968 (Groups 1, 4 and 7) and phase II involving those calved in 1969 (Groups 2, 4, 5 and 7). Groups 1 and 2 calved only once, groups 4 and 5 twice and group 7 three times over the 3 year-period. The purpose of Analysis I was to compare cows with one, two or three calvings, and to examine the factors which determine variation in postpartum interval, conception length and gestation length. Analysis II was divided into 2 phases, phase I included those cows calved in 1968 and 1969 (Groups 4 and 7) and phase II comprised those which calved in 1969 and 1970 (Groups 5 and 7). The main objective was to study first, differences among breeds in calving interval as well as the components of calving interval (postpartum interval, conception length and gestation length) and second, the important factors which cause variation in these reproductive traits.

In Analysis I, phase I, comparisons were made between groups of cows (1, 4 and 7) calved in 1968. The overall mean for postpartum interval and conception length was 86.3 ± 23.4 days and 18.5 ± 14.8 days respectively. Since four breeds are involved in the analysis, estimators of gestation length will be given by breeds rather than years. Average gestation length was 285.2 ± 0.6 days for Hereford, 283.3 ± 0.7 for Brown Swiss, 282.2 ± 0.6 for Angus and 279.8 ± 0.5 for Holstein. Gestation was affected significantly ($P < 0.01$) by breed of cow, farm and breed of sire. Beef cows exceeded dairy cows in gestation length. The lower estimates for length of gestation in dairy cows is partly explained by the fact that only selected data were used in the study. Breed of the sire influenced gestation. Calves of dairy sires showed a shorter gestation period than those from beef sires. Birth weight of the calf was the most important source of variation in gestation length. A regression coefficient of 0.18 pounds per day was found.

Group of cow, breed of cow, farm, sex of the calf and calving period were highly significant sources of variation in postpartum interval ($P < 0.01$). For analysis purposes, cows were classed into 8 calving periods of 14 days, except for period 1 which had 56 days. Calving period 1 corresponding to the earliest calving cows and period 8 to the latest. The length of postpartum interval was 97.5 ± 2.8 days for the group calving twice (Group 4), 96.1 ± 2.7 for those calving once (Group 1) and 88.6 ± 2.5 for those calving three times (Group 7). Breed of cow affected postpartum interval. Means of 100.1 ± 2.7, 96.4 ± 3.6, 93.1 ± 3.2 and 86.8 ± 2.9 days were found for the Holstein, Brown Swiss, Angus and Hereford respectively in the first postpartum interval. Cows on farm 2 had postpartum intervals 11.6 days longer than cows on farm 1. The interval for cows having bull calves was 6.0 days longer than the interval for cows having heifer calves. Calving period was the most influential factor in postpartum interval. The range in postpartum interval according to the calving period extended from 68.3 ± 5.3 (calving period 8) to 120.3 ± 5.4 days (calving period 3). A fixed date in starting the breeding season contributes substantially to this variation.

Conception length was influenced by the breed of cow ($P < 0.05$). Angus, Brown Swiss, Hereford and Holstein cows had means of 23.5 ± 1.7, 18.4 ± 1.6, 17.7 ± 1.5 and 17.0 ± 1.3 days. Synchronization may have lengthened the first conception period.

The overall mean for Analysis I, phase II, (Groups of cows calved in 1969) was 73.2 ± 25.5 days for postpartum interval and 12.3 ± 17.8 days for conception length. Average gestation length was 282.9 ± 0.8 days for Hereford, 281.9 ± 0.7 for Angus, 278.4 ± 0.8 for Brown Swiss and 276.5 ± 0.8

for Holstein. The treatment to conclude gestation explains the lower figures than those reported in the literature especially for Brown Swiss. Gestation period was also affected by farms and breed of sire of the calf and by sex of the calf. The gestation period in farm 2 was 3.4 days longer than in farm 1. The four breeds calved in different proportions on the two farms. Also, more cows on farm 1 were given Azium treatment which contributed to the difference between farms. Azium was effective in inducing parturition, thus shortening gestation periods. The influence of breed of sire of the calf is in agreement with the finding in Analysis I, phase I. On the average, calves from beef sires had a 2.4 day longer gestation period than calves from dairy sires. The effect of sex is not completely understood. Birth weight of the calf was an important source of variation as in phase I. It was the most important factor in explaining the variability in gestation length. A regression coefficient of 0.31 pounds per day was found.

Postpartum interval was very significantly influenced by farm and calving period, and also by treatment in group 7. Cows on farm 1 had a postpartum interval 17.7 days shorter than those on farm 2 ($P < 0.01$). Accurate detection of heat may contribute to the shorter postpartum interval on farm 1. Calving period was responsible for significant differences in postpartum interval. The range in length of postpartum interval extended from 116.7 ± 6.4 to 46.9 ± 10.6 days, depending on whether the cows calved early or late in the season; the same effect was observed in phase I. Animals of group 7 treated with Azium had postpartum intervals 12.4 days longer than those which were not ($P < 0.01$). A consistent effect of Azium or Flucort in lengthening postpartum interval was found in this study.

Conception length was influenced by farms ($P < 0.05$) and group of cow ($P < 0.01$). Animals from farm 2 conceived in 3.6 fewer days than cows on farm 1. Breeding the cows at every heat may lead to an increase in the rate of repeat breeding and therefore in the number of services required for conception. This may explain in part, the longer conception length for cattle on farm 1 and brings under discussion the appropriateness of using services per conception as a measure of fertility. Group of cow had a significant effect on conception length. Those cows which calved only once had the longest conception length. Groups 2 and 5, calving first in 1969 had 23.8 ± 2.7 and 12.0 ± 1.7 days respectively; groups 7 and 4, calving in 1968 and 1969, had 10.7 ± 1.3 and 8.4 ± 1.9 days.

From the results of Analysis I, farm seems to be the most important source of variation. Farm affected postpartum interval, conception length and gestation length. Group of cows had an influence on postpartum interval and conception length.

Breed of cow and sire affected the length of gestation, but birth weight of the calf was the most important source of variation. Treatment to conclude gestation was effective but showed also an effect on postpartum interval.

The results of Analysis II, phase I, which compared groups of cows 4 and 7, gave estimates for the overall means of 374.1 ± 21.5 days for calving interval, 85.3 ± 23.1 for postpartum interval and 10.8 ± 15.4 for conception length. The relative importance of postpartum interval on calving interval was 52.9%, of conception length, 35.2%, and for gestation length, 11.9%. There was no breed difference in calving interval. In contrast, differences in gestation length, postpartum interval and conception length among breeds were highly significant ($P < 0.01$). Average gestation lengths were 282.6 ± 0.8 days for Hereford, 281.5 ± 0.9 for Angus, 278.0 ± 1.7 for Brown Swiss and 277.0 ± 0.8 for Holstein. Lower estimates of length of gestation can be explained in a similar manner as in Analysis I. Birth weight of the calf and, in group 7, the nested effect of treatment where highly significant sources of variation ($P < 0.01$); the effect of treatment in group 4 was only significant at the 5% level. Birth weight of the calf was a very important source of variation in gestation length. A regression coefficient of 0.27 pounds per day was found. Treatment shortened the length of gestation by 2.9 days in group 4 and by 3.0 days in group 7.

Calving interval was affected by farm, calving period and assistance. There was a highly significant difference ($P < 0.01$) of 9.1 days in calving interval between farms. Farm 2 had the longest calving interval. Calving period was responsible for differences in calving interval ranging from 339.6 ± 5.8 days to 402.0 ± 4.4 days. The effect of calving period is due mainly to a fixed breeding period. Cows which received assistance at calving had a 4.5 day longer calving interval than those which did not receive assistance ($P < 0.05$).

The most important source of variation in postpartum interval was group, breed of cow, farm and calving period. Group 4 had a 97.5 ± 3.1 day postpartum interval while group 7 had a 89.0 ± 2.8 day postpartum interval. This difference between groups 4 and 7 was significant at the 1% level. The postpartum interval mean was 102.8 ± 5.1 days for Brown Swiss, 99.7 ± 3.3 for Holstein, 88.3 ± 3.8 for Angus, and 82.0 ± 3.5 for Hereford. Beef cattle had a shorter postpartum interval than dairy cattle ($P < 0.01$). Cows on farm 1 had a postpartum interval of 86.1 ± 2.5 days while cows on farm 2 had a postpartum interval of 100.4 ± 3.7 days. The difference between farms was significant at the 1% level. The length of postpartum interval depends upon the period in which the cows calved. The range in the estimates for postpartum interval according to calving period was from 68.3 ± 8.2 days (period 8) to 118.8 ± 6.1 days (period 2).

Conception length was influenced by assistance given at parturition, by breed of cow, and by breed of the service sire. Heifers (2 years old), which received assistance at calving had a conception length 4.8 days shorter than those which did not ($P < 0.01$). Differences in conception length between breed of cows were noticed. Brown Swiss showed the shortest (4.0 days) compared with the longest for Hereford cows (15.7 days). The shortest conception length for Brown Swiss seems to be due to the fact that fewer Brown Swiss became pregnant. These results do not necessarily portray a characteristic of the breed.

Environmental factors, such as farm, assistance given to the heifers at parturition, calving period, treatment to conclude gestation and birth weight of the calf, are important sources of variability in the four reproductive traits studied. In addition, non-environmental factors such as group and breed of cow, have been shown to be important in explaining differences in reproductive efficiency among cows of four breeds in the first two years of performance.

In Analysis I, phase II, comparisons were made among cows of groups 5 and 7. Cows in group 5 failed to calve in 1968 but calved in 1969 and 1970. Cows in group 7 calved in 1968, 1969 and 1970. Comparisons were made from 1969 and 1970 records. The overall mean was 358.2 ± 28.9 days for calving interval, 73.6 ± 26.3 for postpartum interval, and 7.9 ± 15.2 for conception length; this suggests a rather better reproductive performance for the groups of cows in this period as compared with those included in phase I. The relative importance of postpartum interval on calving interval was 51.1%, for conception length it was 35.0%, and for gestation length it was 13.9%.

The mean lengths of the gestation periods were 279.9 ± 0.7 days for Hereford, 278.5 ± 0.7 for Angus, 277.7 ± 1.0 for Brown Swiss, and 275.7 ± 0.9 for Holstein. These periods tend to be shorter than those in phase I, but the ranking of the four breeds remained the same. Dairy cattle showed again the shortest gestation period. Treatment effect contributed, as in phase I, to the shorter gestation period in dairy cows. Farm, group of cow (5 and 7), treatment and birth weight of the calf were other significant sources of variation in gestation length. The different proportions of breeds calving at the two farms, as well as a partially confounded effect of treatment with breed, explains the 6.4 days difference in gestation length between the two farms. Different proportions of breeds and treatments in the groups account for the 1.7 day difference in gestation period among groups of cows. Birth weight of the calf, as in phase I, was the most important source of variation in gestation length. A regression coefficient of 0.14 pounds per day was found between calf weight and gestation length.

Calving interval was affected by farm, calving period and treatment. A difference of 40.2 days was found between farm 1 and 2 ($P < 0.01$). This larger difference in comparison with phase I is a result of a shorter postpartum interval, conception length, and gestation length on farm 1 than on farm 2. Calving period explained an important part of the variation. The cows which calved latest in the season (calving period 8) had a calving interval of 316.7 ± 14.7 days, while those that calved earliest in the season (calving period 1) had 402.2 ± 7.4 days. Fewer services per conception for the cows calving latest, explain the difference in calving interval between Analysis I and Analysis II. Treatment within group 7 was another important source of variation. Cows receiving the treatment had a 12.9 day longer calving interval than those which did not ($P < 0.01$).

The same factors which affected calving interval were found to be important as well in postpartum interval, since postpartum interval was responsible for a large part of the variation in calving interval. Cows on farm 1 had a 17.9 day shorter postpartum interval than those on farm 2 ($P < 0.01$); a greater effect than the one found for the animals in phase I. The difference between the cows calving earliest and those calving latest was 83.8 days. Cows calving in period 8 had an average postpartum interval 27.0 ± 13.5 days while those calving in period 1 had an interval of 110.8 ± 6.5 days. The fixed breeding date explains the difference between calving periods. A highly significant difference due to treatment of 9.7 days ($P < 0.01$) was found among cows of group 7. Cows which received Azium had the longest postpartum interval.

The only factor which appeared to influence conception length was assistance at calving. On the average, cows receiving assistance at calving had periods 6.1 days longer before the next conception than those which did not. This effect is opposite to the results from phase I. However, in phase II, the effect of assistance was not reflected in calving interval, due to the masking effect of postpartum interval which was a much larger source of variation. The treatment given to the cows to conclude gestation lengthened conception length but the differences were not significant.

Over three years, the calf crops by breeds were 269 (50.0%) for Brown Swiss, 327 (59.4%) for Herefords, 341 (60.3%) for Angus and 366 (64.7%) for Holsteins. The most successful group of cows (group 7 with 3 calvings in 3 years) had shorter postpartum intervals than any other group throughout the period under study. A tendency for shorter conception length was also observed in group 7. Then, the variables effecting a shorter postpartum interval and conception length must not be overlooked in any program for improving reproduction. Breed of cow and assistance to the heifers can shorten both postpartum interval and conception length. On the other hand, treatment to conclude gestation lengthened both periods. Beef cattle showed a tendency for a shorter postpartum interval, while dairy cattle had predominantly a shorter conception length. Gestation length is a reproductive trait in which most of the variability depends on the characteristic of the calf.

Reproductive efficiency is a difficult trait to measure accurately. Many genetic and environmental factors and their interactions are involved. Even in an experimental situation, it is difficult to maintain animals under controlled management conditions. Changes in management could change reproductive performance of the breeds. Without adjustments for the various factors affecting reproductive traits, it is very difficult to make valid comparisons between breeds of cows and to obtain reliable estimates of the different measures of reproductive efficiency. Postpartum interval and conception length are critical periods in the reproductive performance of cows. Thus, in evaluating estimates of reproductive efficiency, factors influencing reproductive performance from parturition to conception must be taken into consideration. Environmental control through farm (management) and treatment to conclude beef industry, but their use needs further study. Assistance to the heifers at parturition needs to be considered. As far as reproductive traits are concerned, dairy breeds performed differently when used in beef production than when used in dairy production.

Evidence for using dairy cows in beef production is not conclusive as far as reproductive performance is concerned. During the years of this study, dairy cows showed a decline in reproductive performance. An alternative to introducing dairy characteristics in the beef industry might be using aritificial insemination from dairy bulls.

LITERATURE CITED

Adams, William M.
1969. The elective induction of labor and parturition in cattle. J. Am. Vet. Med. Ass. 154: 261-265.

Adams, W. M. and W. C. Wagner.
1970. The role of carticoids in parturition. Biology of Reproduction 3: 223-228.

Alexander, M. H.
1950. Length of gestation in the five major breeds of dairy cattle (abstract). J. Dairy Sci. 33: 377.

Andersen, H. and M. Plum.
1965. Gestation length and birth weight in cattle and buffaloes: A review. J. Dairy Sci. 48: 1224-1235.

Anderson, L. L., D. E. Ray and R. M. Melampy.
1962. Synchronization of estrous and conception in the beef heifer. J. Anim. Sci. 21: 449-453.

Aurån, Torbjørn.
1970. Factors affecting fertility in cows (translated title). Agricultural College of Norway, Institute of Animal Genetics and Breeding Report No. 291.

Brakel, W. J., D. C. Rife and S. M. Salisbury.
1952. Factors associated with the duration of gestation in dairy cattle. J. Dairy Sci. 35: 179-194.

Branton, C., W. S. Griffith, H. W. Norton and J. G. Hall.
1956. The influence of heredity and environment on the fertility of dairy cattle (abstract). J. Dairy Sci. 39: 933.

BreDahl, R. L.
1970. Beef-dairy cross-breeding: A study of birth traits. Unpublished Ph.D. thesis. Ames, Iowa, Library, Iowa State University of Science and Technology.

Brown, Lans O., Ralph M. Durham, Estel Cabb and J. H. Knox.
1954. An analysis of the components of variance in calving intervals in a range herd of beef cattle. J. Anim. Sci. 13: 511-516.

Buch, N. C., W. J. Tyler and L. E. Casida.
1955. Postpartum estrus and involution of the uterus in an experimental herd of Holstein-Friesian cows. J. Dairy Sci. 38: 73-79.

Burris, Martin J. and Cecil T. Blunn.
1952. Some factors affecting gestation length and birth weight of beef cattle. J. Anim. Sci. 11: 34-41.

Buschner, F. A., R. E. Johnsson, C. I. Blese and A. A. Spillman.
1950. Measuring reproductive efficiency in dairy cattle (abstract). J. Dairy Sci. 33: 391.

Carman, G. M.
1955. Interrelations of milk production and breeding efficiency in dairy cows. J. Anim. Sci. 14: 753-759.

Casida, L. E. and W. Wisnicky.
1950. Effects of diethylstilbestrol dipropionate upon postpartum changes in the cow. J. Anim. Sci. 9: 238-242.

Casida, L. E., W. E. Graves, J. W. Lauderdale, J. W. Riesen and Syed Saiduddin.
1968. Studies on the postpartum cow. Univ. of Wisconsin, College of Agriculture and Life Sciences Research Bulletin 270.

Chapman, A. B. and L. E. Casida.
1935. Length of service period in relation to production and reproductive efficiency in dairy cows. Amer. Soc. Anim. Prod. Proc. 28: 66-70.

Cochran, W. G.
1954. Some methods for strengthening the common χ^2 tests. Biometrics 10: 417-451.

Collins, W. E., E. K. Inskeep, W. J. Tyler and L. E. Casida.
1962. Variation in conception rates of Guernsey cattle. J. Dairy Sci. 45: 1234-1336.

Cundiff, L. V. and K. E. Gregory.
1968. Improvement of beef cattle through breeding methods. North Central Regional Publication 120.

DeFries, J. C., R. W. Touchberry and R. L. Hays.
1958. Heritability of the length of the gestation period in dairy cattle. J. Dairy Sci. 42: 598-606.

Donald, H. P. and W. S. Russell.
1968. Some aspects of fertility in purebred and crossbred dairy cattle. Anim. Prod. 10: 465-471.

Everett, R. W., and W. T. Magee.
1965. Maternal ability and genetic ability of birth weight and gestation length. J. Dairy Sci. 48: 957-961.

Everett, R. W., D. V. Armstrong and L. J. Boyd.
1966. Genetic relationship between production and breeding efficiency. J. Dairy Sci. 49: 879-886.

Foote, R. H. and A. C. Hall.
1954. Relationship between number of services and per cent nonreturns, calving rates and sex ratio in artificial breeding (abstract). J. Dairy Sci. 37: 673.

Foote, R. H.
1970. Inheritance of fertility - Facts, opinions and speculations. J. Dairy Sci. 53: 936-944.

Gaines, W. J. and J. R. Palfrey.
1931. Length of calving interval and average milk yield. J. Dairy Sci. 14: 294-306.

Gaines, J. A., W. H. McClure, D. W. Vogt, R. C. Carter and C. M. Kincaid.
1966. Heterosis from crosses among British breeds of beef cattle. Fertility and calf performance to weaning. J. Anim. Sci. 25: 5-13.

Gier, H. T. and G. B. Marion.
1968. Uterus of the cow after parturition: involution changes. Am. J. Vet. Res. 29: 83-96.

Graves, E. W., J. W. Lauderdale, E. R. Hauser and L. E. Casida.
1968. Effect of suckling and interval to breeding. In Studies on the postpartum cow. Univ. of Wisc., College of Agric. and Life Sciences Research Bulletin 270.

Hafez, E. S. E.
1968. Reproduction in farm animals. Second edition. Philadelphia, Pa., Lea & Febiger.

Harvey, W. R.
1960. Least squares analysis of data with unequal subclass members. U. S. Dept. Agr. ARS 20-8.

Inskeep, E. K., W. J. Tyler and L. E. Casida.
1961. Hereditary variation in conception rate of Holstein-Friesian cattle. J. Dairy Sci. 44: 1857-1862.

Jafar, S. M., A. B. Chapman and L. E. Casida.
1950. Causes of variation in length of gestation in dairy cattle. J. Anim. Sci. 9: 593-601.

Johansson, Ivor.
1961. Genetic aspects of dairy cattle breeding. Urbana, Illinois, University of Illinois Press.

Johnson, A., R. M. Meyers and L. C. Ulberg.
1964. Method for evaluating reproductive status in a dairy herd (abstract). J. Dairy Sci. 47: 341.

Kennedy, P. C., J. W. Kendrick and C. Stormont.
1957. Adenohypophyseal aplasia - An inherited defect associated with abnormal gestation in Guernsey cattle. Cornell Vet. 47: 160-178.

Knapp, Bradford, Jr., W. V. Lambert and W. H. Black.
1940. Factors influencing length of gestation and birth weight in cattle. J. Agr. Res. 61: 277-285.

Konce, K. L.
1968. Association of birthweight and gestation length with preweaning growth in beef cattle. Unpublished Ph.D. thesis. Raleigh, North Carolina, Library, North Carolina State University at Raleigh, N. C.

Krehbiel, E. V., R. C. Carter, K. P. Bavard, J. A. Gaines and B. M. Priodi.
1969. Effect of inbreeding and environment on fertility of beef cattle matings. J. Anim. Sci. 29: 528-533.

Lasley, J. F., B. N. Day and J. E. Comfort.
1961. Some genetic aspects of gestation length, and birth and weaning weights in Hereford cattle. J. Anim. Sci. 20: 737-741.

Lauderdale, W. J., W. E. Graves, E. R. Hauser and L. E. Casida.
1968. Effect of suckling and interval to breeding. In Studies on the postpartum cow. Univ. of Wisc., College of Agric. and Life Sciences Research Bulletin 270.

Legates, J. E.
1954. Genetic variation in services per conception and calving interval in dairy cattle. J. Anim. Sci. 13: 81-88.

Livesay, E. A. and V. G. Bee.
1945. A study of the gestation periods of five breeds of cattle. J. Anim. Sci. 4: 13-14.

Lush, J. L.
1945. Animal breeding plans. Third edition. Ames, Iowa, The Iowa State University Press.

Maijala, K.
1964. Fertility as a breeding problem in artificially bred populations of dairy cattle. I. Registration and heritability of female fertility. Annales Agricultural Fenniae Vol. 3, supplementum 1.

Mason, I. L.
1966. Hybrid vigour in beef cattle. Anim. Breed. Abstr. 34: 453-473.

McDowell, R. E., G. V. Richardson, B. E. Mackey and B. T. McDaniel.
1970. Interbreed matings in dairy cattle. V. Reproductive performance. J. Dairy Sci. 53: 747-763.

Menge, A. C., S. E. Mares, W. J. Tyler and L. E. Casida.
1962. Variation and association among postpartum reproductive and production characteristics in Holstein-Friesian cattle. J. Dairy Sci. 45: 233-241.

Morrow, D. A., S. J. Roberts, K. McEntee and H. C. Gray.
1966. Postpartum ovarian activity and uterine involution in dairy cattle. J. Am. Vet. Med. Ass. 149: 1596-1609.

Olds, D. and D. M. Seath.
1950. Predictability of breeding efficiency in dairy cattle. J. Dairy Sci. 23: 721-724.

Olds, D. and D. M. Seath.
1953. Repeatability, heritability and the effect of level of milk production on the occurrence of first estrus after calving in dairy cattle. J. Anim. Sci. 12: 10-14.

Ødegård, A. K.
1965. A study of some factors affecting reproductive efficiency in Norwegian red cattle. Acta Agr. Scand. 15: 204-212.

Pearson, L. and R. E. McDowell.
1968. Crossbreeding of dairy cattle in temperate zones: a review of recent studies. Anim. Breed. Abstr. 36: 1-7.

Pirchner, Franz.
1969. Extended gestation in Pinzgau cows. Annales de Génétique et de Selection Animale 1: 27-31.

Plum, M. H., Henry Anderson and L. A. Swiger.
1965. Heritability estimates of gestation length and birth weight in Holstein-Friesian cattle and their use in selection indexes. J. Dairy Sci. 48: 1672-1675.

Pou, J. W., C. R. Henderson and S. A. Asdell.
1953. A study of the inheritance of breeding efficiency in the Beltsville dairy herd. J. Dairy Sci. 26: 909-915.

Rennie, J. C.
1952. Causes of variation in calving interval of Holstein-Friesian cows. Unpublished Ph.D. thesis. Ames, Iowa, Library, Iowa State University of Science and Technology.

Riesen, J. W., Syed Saiduddin, W. J. Tyler and L. E. Casida.
1968. Effect of suckling. In Studies on the postpartum cow. Univ. of Wisc., College of Agric. and Life Sciences Research Bulletin 270.

Rollins, W. C., R. C. Laben, S. W. Mead.
1956. Gestation length in an inbred Jersey herd. J. Dairy Sci. 39: 1578-1593.

Rollins, W. C., R. G. Roy, F. D. Carroll and K. A. Wagner.
1969. Heterotic effects in reproduction and growth to weaning in crosses of the Angus, Hereford and Shorthorn breeds. J. Anim. Sci. 28: 431-436.

Rollinson, D. H. L.
1955. Hereditary factors affecting reproductive efficiency in cattle. Anim. Breed. Abstr. 23: 215-249.

Sagebiel, Joe A., G. F. Krause, Bob Sibbit, L. Langford, J. E. Comfort, A. J. Dyer and John F. Lasley.
1969. Dystocia in reciprocally crossed Angus, Hereford and Charolais cattle. J. Anim. Sci. 29: 245-250.

Saiduddin, Syed, J. W. Riesen, W. J. Tyler and L. E. Casida.
1968. Effect of suckling, feeding level, breeding management and genetic level of milk production. In Studies on the postpartum cow. Univ. of Wisc., College of Agric. and Life Sciences Research Bulletin 270.

Scheffé, Henry.
1959. The analysis of variance. New York, N. Y., John Wiley and Sons, Inc.

Smith, W. J. and J. E. Legates.
1962. Relation of days open and days dry to lactation milk and fat yields. J. Dairy Sci. 45: 1192-1198.

Spielman, A. and I. R. Jones.
1939. The reproductive efficiency of dairy cattle. J. Dairy Sci. 22: 329-334.

Tabler, Kenneth A., W. J. Tyler and George Hyatt Jr.
1951. Type, body size and breeding efficiency of Ayrshire cow families. J. Dairy Sci. 34: 95-105.

Terril, C. E. and L. N. Hazel.
1947. Length of gestation in range sheep. Am. Jour. Vet. Res. 8: 66-72.

Tudorascu, R.
1968. Study of conception rate, insemination index and length of service period in cows inseminated during different periods after pasturition (translated title). Revta. Zooth. Med. Vet. 7: 34-43.

Turner, J. W., B. R. Farthing and George L. Robertson.
1968. Heterosis in reproductive performance of beef cows. J. Anim. Sci. 27: 336-338.

VanDemark, N. L. and S. W. Salisbury.
1950. The relation of the postpartum breeding interval to reproductive efficiency in the dairy cow. J. Anim Sci. 9: 306-313.

VanDemark, N. L.
1954. Management practices and fertility in dairy herd. Calif. Vet. 7: 24-25.

Wagner, W. C. and William Hansel.
1969. Reproductive physiology of the postpartum cow. I. Clinical and histological findings. J. Reprod. Fert. 18: 493-500.

Wilcox, C. J., K. O. Pfau and J. W. Bartlett.
1957. An investigation of the inheritance of female reproductive performance and longevity and their interrelationships within a Holstein-Friesian herd. J. Dairy Sci. 40: 942-947.

Williams, W. L.
1919. A standard for measuring the reproductive and dairying efficiency of cattle. Cornell Vet. 4: 204-213.

Wiltbank, J. N. and A. C. Cook.
1958. The comparative reproductive performance of nursed and milked cows. J. Anim. Sci. 17: 640-648.

Wiltbank, J. N., K. E. Gregory, J. A. Rothlisburger, J. E. Ingalls and C. W. Kasson.
1967. Fertility in beef cows bred to produce straightbred and crossbred calves. J. Anim. Sci. 26: 1005-1010.

Wright, J. M., I. Seltergen, R. R. Saatman and W. Hansel.
1970. Peripheral plasma progesterone levels in pregnant cows treated with flumethasone. Society for the Study of Reproduction (abstracts) 3: 32.

Zimbelman, R. G. and L. W. Smith.
1966. Control of ovulation in cattle with melengestral acetate. J. Reprod. Fert. 11: 185-191.

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